A Survey of 20 Atlantic Salmon Farms in the Bay of Fundy: Influence of Environmental and Husbandry Variables on Performance

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p. 4, 2nd column, 5th paragraph, 5th line. *Should read* : As an example, we show one for site 66, the most exposed, in Fig. 2.

p. 5, 2nd column, 2nd paragraph, 4th line. *Should read* : This is apparent in Fig. 4 ....

p. 23, 1st column, 3rd paragraph, 2nd line. *Should read* : All of the discussion to this point assumes that the distributions of smolt and caged fish sizes are.....

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ABSTRACT

Peterson, R. H., F. Page, G. D. Steeves, D. J. Wildish, P. Harmon, and R. Losier. 2001. A survey of 20 Atlantic salmon farms in the Bay of Fundy: influence of environmental and husbandry variables on performance. Can. Tech. Rep. Fish. Aquat. Sci. 2337: v + 117 p.

In 1995 a survey of 20 salmon farms was initiated to study environmental and husbandry factors affecting farm performance. Three cages were monitored on each of the 20 farms. For each of these cages, the 1995 smolt year-class was followed from smolt entry to harvest (1995-97). Although the identity of the 20 farms will be anonymous, the survey included farms on Grand Manan Is. (2), Campobello Is. (2), Deer Is. (5), Passamaquoddy Bay (1), and 10 farms scattered along the southwestern New Brunswick coast of the Bay of Fundy in the Letang-Lime Kiln area.

Environmental variables measured were temperature at 3 m depth (half-hourly over the 2 yr of the study), water depth (from bathymetry), water currents, dissolved oxygen concentration (24 h continuous in August-September of the second summer), and farm site exposure. Husbandry variables measured were: cage type and volume; smolt size, source, sex ratio and stocking density; feed types and volumes on a monthly basis (from farmers' log books); feeding rates in each of the two summers of the growth cycle; surface area of the cage covered during feeding; and harvest strategy. Performance indicators measured included: growth rates (fish size estimated once each summer by a stereoscopic video system); monthly mortalities due to various causes; feed conversion efficiencies at various points in the growth cycle; estimates of fish swimming velocity; incidence of sexual maturation in harvested fish; incidence of various deformities in harvested fish; biomass of fish harvested; and fin condition of harvested fish. Exploratory data analysis techniques included regresssion, cluster analysis (centroid), and discriminate function analysis to determine variables important in assigning cages to clusters.

In general, husbandry variables were more influential determinants of farm performance than environmental variables. Initial smolt size accounted for about 60% of the variance in growth rates among cages over the first year. Cage shape and size affected growth, feed conversion efficiency, and swimming speed, with fish monitored in the large plastic circles performing best on average.

RÉSUMÉ

Peterson, R. H., F. Page, G. D. Steeves, D. J. Wildish, P. Harmon, and R. Losier. 2001. A survey of 20 Atlantic salmon farms in the Bay of Fundy: influence of environmental and husbandry variables on performance. Can. Tech. Rep. Fish. Aquat. Sci. 2337: v + 117 p.

En 1995, un relevé a été effectué dans 20 piscifactures de saumon afin d'étudier les facteurs de l'environnement et de l'élevage influant sur le rendement des piscifactures. Dans chacune des 20 piscifactures, l'étude a porté sur trois cages où nous avons suivi l'évolution des smolts de la classe d'âge de 1995 à partir du niveau de smolt à l'arrivée jusqu'à la récolte (1995-1997). Même si l'identité des vingt piscifactures demeure secrète, disons que le relevé a porté sur des piscifactures de l'île Grand Manan (2), de l'île Campobello (2), de l'île Deer (5), de la baie Passamaquoddy (1) et sur dix piscifactures disséminées le long de la côte de la baie de Fundy baignant le Sud-Ouest du Nouveau-Brunswick dans la région de Letang-Lime-Kiln.

Les variables environnementales mesurées ont été la température à 3 m de profondeur (à toutes les demi-heures au cours des deux ans qu'a duré l'étude), la profondeur de l'eau (bathymétrie), les courants, la concentration d'oxygène dissous (24 h sur 24 en continu d'août à septembre pendant le deuxième été) et l'exposition de la piscifacture aux éléments. Les variables d'élevage étudiées étaient : le type de cage et son volume; la taille des smolts, leur provenance, la proportion relative des sexes et la densité de stockage; les types et la quantité de nourriture par mois (données extraites des journaux de bord des exploitants); les taux d'alimentation

l'alimentation et la stratégie de récolte. Voici les indicateurs de rendement qui ont été mesurés : taux de croissance (taille des poissons estimée une fois par été par un système stéréoscopique vidéo); taux de mortalité mensuel attribuable à diverses causes; efficacité de la conversion des aliments à divers moments du cycle de croissance; estimations de la vélocité des poissons; incidence de la maturation sexuelle des poissons récoltés; incidence de diverses difformités dans le poisson récolté; biomasse du poisson récolté; et état des nageoires du poisson récolté. Les techniques d'analyse des données exploratoires comprenaient l'analyse de la régression, l'analyse des grappes (position centroïde) et l'analyse de la fonction de discrimination afin de déterminer les variables importantes dans l'affectation des cages aux diverses grappes.

En règle générale, les variables d'élevage étaient des déterminants plus probants du rendement des piscifactures que les variables environnementales. La taille initiale des smolts représentait environ 60 % de la variation dans les taux de croissance entre les cages au cours de la première année. La forme et la taille des cages avaient une incidence sur la croissance, l'efficience de la conversion des aliments et la vitesse de déplacement des poissons; en moyenne les poissons observés dans les grands dômes de plastique étaient ceux qui performaient le mieux.

INTRODUCTION

The Bay of Fundy salmon aquaculture industry began in the late 1970s, and featured dramatic growth in the 1980s. The growth of the industry levelled off somewhat in the late 1990s at around 20,000 metric tonnes (MT), valued at around 100-120 million dollars (New Brunswick Salmon Growers Association (NBSGA), pers. commun.).

Prices obtained for salmon have declined with maturation and growth of the industry, forcing farmers to increase production and production efficiency. The need for increasing competitiveness of the industry prompted the initiation of a study of salmon farming to examine husbandry practices, and possibly to identify those that were important to farm production and efficiency. To this end, the cooperation of 20 farmers was obtained, which allowed us to follow the 1995 year-class from smolt entry to harvest. The objective of the study, therefore, was to identify husbandry practices and environmental variables of particular importance to production efficiency.

Parameters that can be measured on salmon farms can be assigned to one of three classes: environmental variables, husbandry variables, or performance indicators. Important environmental variables include temperature, water current exchange, farm exposure, and dissolved oxygen. Husbandry variables are many and complex, and include cage size, smolt size, feeding strategies and rations, and stocking densities. Many performance indicators are the same as those of many ecosystems, and include growth rate, mortality, biomass increase, sexual maturation, time to market size and size at marketing.

In order to identify potential patterns in the variables and relationships among the variables, exploratory analyses of the data were conducted along one of two lines. First, the relative importance of variables could often be determined by regression analysis. Second, discriminate function and cluster analysis were used to cluster farms or cages based upon environmental or husbandry variables, to identify significant discriminate functions used in identification of clusters, and to identify which variables were significantly correlated with the discriminate functions.

In view of the possible wide range of interests of potential readers - from aquaculturists to researchers - we have attempted to make the presentation of statistical analyses as streamlined as possible, relying, in most cases, on graphical presentations or tables of statistical summaries. It is hoped that this will make the information more accessible to the non-scientist.

METHODOLOGY

FARM SELECTION

Salmon farms were selected from a list of NBSGA members, with an attempt to have reasonable representation from all major geographic areas. The selected farms were assigned a random code to preserve their confidentiality. It was desired to ensure that various geographical areas were represented: 2 farms from Grand Manan, 2 from Campobello, 5 from Deer Island, and the remaining 11 from various embayments on the New Brunswick mainland. Since a major portion of the funding for the project was provided by an AFAP grant to the NBSGA, it was also required that each of the selected farms be a member of that association. The owners of each of the selected farms were then contacted to elicit their cooperation in the project. The response was very positive; only 22 farms had to be contacted to obtain the participation of 20 farms.

CAGE SELECTION

For logistic reasons, it was decided to monitor three cages on each farm. The selection of the cages to be monitored was, by and large, decided by the participating farmers. The criteria for cage selection varied among the farmers. Frequently three cages with differing smolt sizes were selected; although on one farm, the smolt size class was identical for the three cages. In some cases, cages receiving smolts from different hatcheries were selected.

SMOLTS

Samples of 20 smolts from each of the 60 cages were requested, with the farmers being compensated for the smolts obtained from them. The smolts were obtained from the hatchery trucks at the point where they were to be transferred to the boats used to ferry them to the farms in April-May 1995. Cooperation of the various hatcheries during coordination of smolt acquisitions was excellent. Schedules were frequently hectic for this part of the project, with the requirement to make simultaneous

pick-ups at different wharves being of regular occurrence. The smolts were transferred back to the laboratory in standard fibreglass hatchery cans containing 100 L of aerated fresh water from the hatchery truck. For some of the longer trips, as for example from Grand Manan, ice was placed in the lids of the hatchery cans to prevent heating during transit. Out of 60 possible smolt samples, 56 were collected, amounting to 1120 smolts available for analysis.

Ten of the 20 smolts in each sample were used in salinity challenge tests, wherein the smolts would be exposed to a salinity of 37 psu for 96 h to assess the mortality resulting from salinity stress. The test containers (ca. 100-L capacity) were in water baths receiving a flow of seawater at ambient temperature (5-7°C). A total of 44 tests were considered valid.

Some smolt samples were obtained after the fish had been placed in the sea cages, rendering a salinity challenge invalid. In one series involving three samples, an error in mixing the saline bath occurred, and with another sample the air line had not been inserted properly.

The remaining 10 smolts from each sample were sacrificed by stunning, weighed, measured to fork length, sexed, and inspected for adhesions, deformities, fin condition, and possibility of precocious sexual maturation. Fin condition was rated for dorsal fin, paired fins, and caudal fin. Operculum was rated as well. A perfect appendage was given a rating of 0.0, with values of 0.5-2.0 assigned to increasing severity of damage, with 2.0 indicating total fin (or opercular) loss. Thus, a perfect fish would receive a score of 0.0, while the worst possible score would be 8.0.

CAGE OBSERVATIONS

Husbandry variables

Feeding of salmon in surveyed cages was observed on about 120 occasions (2 visits to each of 60 cages). The length of time during which fish were fed (= feeding time), the length of time during which fish "boiled" (broke the water surface) at the surface during feeding (= "boiling time"), and the total standardized dry weight of feed (expressed here as kilograms of moisture-free feed, assuming 7% moisture for dry diets and 22% moisture for moist diets (J. Castell, pers. commun.)) that was administered to each cage at a single feeding were measured. In a few instances, the farmer would feed a particular cage for awhile, then return to it for further feeding after feeding other cages. The feeding times given here are the total times during which active feeding was carried out. The calculated feeding rates (in grams of feed per kilogram of fish biomass per 100 s) represent an average rate at which feed was delivered to the cage. The feed was usually fed in pulses, with pulses usually more frequent during the beginning of the feeding periods. Use of medicated feed was recorded.

Two visits were made to each cage in the project, once in the first summer (July-September 1995), and once early in the second summer (late May-early July 1996). Each visit coincided with the first feeding of the fish on the day of the visit. The time of feeding for each cage and the amount of food provided at the feeding were recorded, as well as the feed type. The surface area of the cage that received food was estimated subjectively by shading a map of the extent of cage area over which feed fell, and the duration of the feeding period when fish "boiled" at the surface was recorded. The apparent swimming speeds of 10 fish were estimated by measuring with a stopwatch the time required for the fish to swim a measured distance around the periphery of the cage. This resulted in an apparent swimming speed, because it does not take water velocity into account. A synchronized dual video camera system (Steeves et al. 1998) was lowered into each cage, and the fish were taped for 30 min at each of 2 depths - "shallow" (1-2 m) and "deep" (3-5 m). From these tapes, fish size was estimated by image analysis.

In addition to the above observations, the farmers provided data on the numbers and average sizes of smolts placed in each cage, cage depths, mesh sizes, feed sources, feeding frequencies. Also, farmers were requested to provide monthly summaries of mortality, rations, and kind and timing of prophylactic usage. Complete records were obtained from 14 of the 20 farms.

Environmental variables

Temperature was measured with MINILOG-TRs (manufactured by VEMCO Ltd, Shad Bay, Nova Scotia, Canada). The instruments were moored at 5 m below the sea surface by attaching them to weighted lines tied to the site infrastructure. The instruments respond to

temperatures between –2 to 20°C, with an accuracy of ±0.1°C and a resolution of 0.16°C, respectively. The instruments were periodically calibrated by placing them in a temperature bath of known temperature. Prior to deployment, the instruments were programmed to record the instantaneous temperature every 30 min. Since the cost of the instruments was relatively low, a recorder was maintained on each farm for the entire duration of the study. Individual instruments were replaced every 3-4 mo to ensure the internal memory was not filled and to help achieve a high success rate of instrument and data recovery.

The speed and direction of the water current at each site was measured by deploying an InterOcean S4 5 m below the sea surface in close proximity to the cages on a farm site. The instrument was programmed to internally store a 5-min average of the current every 5 min. The duration of each deployment was about 24 h, which is about two tidal cycles. Although longer time series and records from multiple locations within each site would have been desirable, the high cost and limited availability of the instrument precluded longer and more numerous deployments.

Dissolved oxygen was measured with an Orion Model 840 Dissolved Oxygen Meter with a 2-electrode, temperature-compensated probe. The meter output was led into a Model 4510 strip chart recorder (The Recorder Company). Dissolved oxygen was measured continuously for a 24-h period at each site at 3 m depth in late August 1996, when biomass and temperature were higher. Difficulties with the recorder resulted in only five complete records.

Harvesting

As farmers harvested fish from each of the monitored cages, they were requested to inform us 24 h in advance, to allow us to sample harvested fish at the processing plants. A total of 142 trips were made to nine processing plants. The cooperation of the various processing plants in providing facilities for sampling fish was excellent.

On each visit, 50 fish were grab-sampled from the top of a single "Exactix" tank used to ship fish to the processor. Since the fish were immersed in an ice-brine slurry, only a few on the top could usually be seen. This minimized any possible selection. Each of the 50 fish were weighed, measured, graded for fin (caudal, dorsal, paired) and operculum condition. Incidences of deformities (scoliosis, jaw deformities, compressed caudal peduncle) were recorded. A numbered tag was attached to the caudal peduncle of each sampled fish with an elastic band, and the fish placed in a reserved tank of ice-brine mix. This tank of sampled fish was dumped onto the processing line when convenient, and the sex and state of maturity of each fish was recorded as they were gutted. Muscle lipid levels were measured on some processed fish samples with a Torry Model 692 fat meter.

RESULTS

ENVIRONMENTAL VARIABLES

Various environmental variables may be influential in the performance of salmon farms. We performed measurements on four of possible importance: temperature, water currents, depth, and exposure. Another - dissolved oxygen - was investigated in a very cursory fashion, and deserves further study.

Temperature

Temperature records were obtained from most farms for about 3 yr. The data are too numerous to include the raw observations in this report. The dominant features of each complete record were the seasonal and tidal cycles. The annual range of temperature at each farm was 10-15°C and variation over a tidal cycle was about 1°C. Absolute temperatures, for the study as a whole, ranged between 0.5 and 15.2°C (Table 3). The lowest temperatures occurred in February and March, the warmest in August and September. At any instant in time, the variation in temperature among farms ranged from near 0°C in the spring and fall to about 6°C during the summer. This spatial variation in temperature is thought to be associated with the proximity of farms to extensive intertidal areas. The water over intertidal areas warms relative to offshore water in the summer due to solar heating and heating from the substrate. The water cools in the winter due to heat loss. Hence, farms that are close to extensive intertidal areas experience higher seasonal highs and lower seasonal lows than farms less influenced by the intertidal heating effect (Fig. 1; existing fig. 4). The spatial and temporal differences in the temperatures among the sites

resulted in the growing degree-days varying from a low of 2103 d to a high of 2366 d, a difference of 263 degree-days. Assuming a mean temperature of 10°C makes this equivalent to about 20 calendar days. Details of the temperature records for each site will be published in a subsequent report.

Water currents

The 5-min average current speeds measured during the study ranged from 0-42 cm s^{-1} and the mean speeds, calculated over the duration of the deployments, ranged from 2.6-17.6 $cm \cdot s^{-1}$ (Table 3). The net water displacement (Table 3), estimated as the cumulative vector sum of velocity x time for a 24-h period, ranged from 0.9-11.0 km, and indicates how far a parcel of water would travel over a 24-h period (~2 tidal cycles). These observations suggest that some farms experience significant periods of time when water renewal within the site and within the cages is minimal, and that a significant proportion of the water within a site may be returning to the site on adjacent tidal cycles. Details of the current speeds for each site will be published in a subsequent report.

Exposure

We define exposure as the degree to which a farm site is exposed to the action of wind - it is the opposite of shelter. Exposure has two components: the extent of open water between the site and the nearest point of land in a given compass direction, and the accumulated wind vectors blowing from that compass direction over the course of a year. In this regard, we have used 1995 as the reference year for this study. In Table 1 we show the accumulated wind vectors for each of the compass points for each month of the year (based on data sheets from the weather office at the Saint John airport). For example, the accumulated wind vector from the north in December amounted to 1992 km. Thus, an average December wind speed of 2.7 $km \cdot h^{-1}$ from the north, multiplied by the number of hours in December (744), would give the vector shown in Table 1. Actually, of course, the wind does not blow at a constant velocity - but the example illustrates how the wind vectors were obtained.

If we sum the monthly wind vectors from a given compass point, we obtain an accumulated annual wind vector, shown on Table 1. We can see from the totals that the compass directions with the highest annual accumulated wind vectors are SSW, N, NW, and NNW. The highest monthly vectors from the north to west quadrant are in the winter months, while those from the south-southwest are highest in the summer.

The totals for each month are shown on the far right of Table 1. Generally, the winter months (Nov.-Mar. inclusive) have higher totals than the summer months.

We then divided the annual accumulated wind vectors by the smallest one (2328 km in the ENE sector) to provide a reasonably small number to work with. This is an annual accumulated wind vector index. It can be seen that for 1995, the total wind from the north was 5.65 times that from the east-northeast.

We next multiplied the annual accumulated wind vectors by the distance of open water from each farm site in the survey to the nearest land for each compass point. Any distance greater than 5000 m was arbitrarily taken as 5000 m, assuming that the exposures at distances greater than 5000 m would be no more severe than those at 5000 m. These values for each farm are shown in Table 2. For example, the component of the exposure index for site 49 from the north amounted to 452 x 10^3 m^2, with the total for all compass points being 11,662 x 10^3 m^2. We divided each of the totals by 10,000 - again to produce a relatively small number to work with - shown in Table 2 on the far right. The units are in hundredths of a km^2. Site 66 was the most exposed, with an index of 23.5, while 49 was the most sheltered, with an index of 1.2.

By graphing the exposure index components for each of the compass point sectors, an exposure profile could be shown for each site, with the site at the centre of the graph. As an example, we show one for site 66, the most exposed, in Fig. 1. Almost all the wind hitting site 66 comes from the west to north quadrant - probably mostly in winter.

Dissolved oxygen

Dissolved oxygen (DO) levels in salmon cages may be important at certain times in the growth cycle, particularly during periods of high temperature or high cage biomass. The months of August and September are probably most important in this regard, as temperatures are high then, cages containing pre-market fish have high biomass

densities and saturated DO concentrations are lower at higher temperatures.

We attempted to measure DO levels over one 24-h period at each of the participating farms in August and September of 1996. Complete records were obtained from 5 of the 20 farms; difficulties with the strip chart recorder resulted in only partial records at 15 of the 20 farms. At 6 farms, spot checks were obtained at the time personnel were at the site. Although the data are very fragmented, we summarize the maximal and minimal DO levels recorded at the 20 farms in Fig. 3. For 11 of the farms, maximal recorded oxygen never attained saturation levels (Fig. 3A). Minimal recorded levels averaged about 70% saturation, with 50% saturation or less observed at a couple of farms (Fig. 3B).

The five complete records typically exhibited a range of saturation values of about 10% over the 24-h recording period (e.g. 80-90% saturation). One farm showed two periods of about 4 h each of depressed O_2 from 100% down to 70-75% saturation at dawn and dusk, corresponding perhaps to peak locomotion periods. The other four records were somewhat more uniform.

Water depth

Water depth was determined from bathymetric maps - local variation might mean that these values are not precise for the exact location of a particular cage. Depths ranged from 8-25 m (Table 3).

CLUSTERING OF SALMON FARMS BASED ON PHYSICAL VARIABLES

A cluster analysis was performed on the 20 farms, using the physical variables of Table 3. This analysis lumps together farms that are most alike, taking all these variables into account, with similar farms clustering together. Specifically, agglomerative centroid clustering, based on Euclidean squared distances, was used (SPSS statistical package). We did two analyses, one on the original data. However, as will be indicated, this presents a biased picture because some variables have a wider range of values than others do, so that they are more influential in determining the clusters. A second analysis used variables scaled from 1-10, so they all have equal weighting in the analysis. The lowest value of each variable was assigned a value of 1, and the highest a value of 10. The other values were calculated based on where they were located in relation to the high and low values. For example, with maximum temperature, farm 81 had the lowest maximum (12.1°C), while farm 41 had the highest (15.2°C) - the difference between the two being 3.1°C. Farm 66 had a maximum temperature of 14.2°C, 2.1°C higher than the lowest value. Its transformed value would be (2.1/3.1)*9 + 1 = 7.2.

When the original data are used, the cumulative degree-days variable is most influential because it has the widest range of values. This is apparent in Fig. 3 where the clusters are shown on a grid of mean current speed vs. cumulative degree-days. The clusters are aligned along the degree-day axis. Cluster 2 contains farms with the fewest degree-days. Farms 66 and 41 are outliers with high degree-day accumulation. Obviously, current speed had little influence in assigning farms to clusters, as each cluster is spread over a wide range of currents. Similarly, most other variables are of lesser influence. Clusters 1 and 2 are mostly Grand Manan, Campobello, and Deer Island with a couple of mainland farms outside Lime Kiln Bay. Clusters 3 and 4 are Lime Kiln farms. Within a cluster, some farms are more closely linked than others are. For example, 43 and 35 are enclosed within a cell inside cluster 1.

When the farms were clustered using the environmental variables scaled from 1-10, determining which variables were important in assigning farms to clusters was no longer straightforward. More complex combinations of variables were involved. A discriminant function analysis was therefore performed on the clusters to determine statistically which variables were most highly correlated with cluster delineation. These functions are combinations of all the variables calculated in such a way as to minimize the variability in the data. Four significant discrimination functions were obtained (Table 4), which accounted for 98% of the variance among clusters. The first discriminant function was significantly correlated with cumulative degree-days (Table 5), the second with minimum and maximum temperatures and water current, the third with no single variable, and the fourth with exposure and water displacement. The clusters of sites are plotted in relation to the first two discriminant functions in Fig. 5. Cluster 1 is a group of farms characterized by relatively high current velocities, high minimum winter temperatures and low summer maximum temperatures. Cluster 2 contains four farms that are

well sheltered, and have below average current velocities. Cluster 3 is composed of "average" farms in most categories - mostly Lime Kiln Bay sites. Sites 26, 66, and 41 are outliers - unusual sites with either unusually high summer temperature maxima (and low winter minima) or unusually high current velocities.

HUSBANDRY VARIABLES

Cage characteristics

The cages monitored in the survey reflected the industry trend toward larger, plastic cages, which are gradually replacing the older, wooden types, and perhaps the steel models as well (Fig. 6). The 70-m circumference, circular, plastic cage was the single most numerous cage type in the survey. The variation in calculated volumes reflect the different net depths reported by different farmers - ranging from 5.0-9.5 m. The volumes listed are maximal values as net deformation by tidal currents usually reduced the cage volume to a variable degree.

Stocking densities

Numbers of smolts stocked in the cages ranged usually between 4 and 12 smolts per cubic meter of cage volume (Fig. 7, 8). Almost half the cages in the study (26) received 3-6 smolts$\cdot m^{-3}$ (Fig. 7). The number of smolts installed in a cage was related to rearing strategy - whether or not the fish would eventually be divided among two or more cages. This strategy is frequently used when the farmer has insufficient space when smolts are installed, but space will become available as older fish are subsequently harvested. Initial biomass stocking densities ranged from less than 0.2 to over 2 kg$\cdot m^{-3}$ (Fig. 8). Initial stocking densities were not related to cage type.

Cages that received smolts at the final desired densities (not to be split) usually received 4-8 smolts$\cdot m^{-3}$, while cages to be split usually received more than 8 smolts$\cdot m^{-3}$ (Fig. 9).

Initial biomass stocking densities were dependent both on number of smolts installed per m^3 and average smolt size. Farmers did not compensate for initial smolt size by installing lower densities of larger smolts Fig. 10), as initial biomass densities are only a small fraction of the eventual densities prior to harvest.

Initial biomass densities for unsplit cages were 0.2-0.3 kg$\cdot m^{-3}$ for 40- to 60-g smolts to over 1 kg$\cdot m^{-3}$ for smolts averaging over 120 g mean weight. The equation relating biomass density to smolt size is:

$$\text{Initial biomass density} = -0.277 + 0.00938 * \text{mean smolt size} \quad (R^2 = 0.67;\ p<0.001).$$

Biomass densities in cages to be split averaged 0.51 kg$\cdot m^{-3}$ more than for unsplit cages (difference in intercepts) for smolts of a given size, the regression for split cages being:

$$\text{Initial biomass density} = 0.232 + 0.00849 * \text{mean smolt size} \quad (R^2 = 0.41;\ p<0.001).$$

The slopes of the regressions for split and unsplit cages are not significantly different. There was more variability in initial biomass densities for cages to be split, possibly because the number of final cages was variable, although usually there were two final cages. The mean smolt size did not differ significantly between cages to be split and those not (87 vs. 89 g).

Smolt characteristics

Samples of 20 smolts from each of the cages to be monitored were requested. Out of 60 possible smolt samples, 56 were collected. Smolt deliveries to the monitored cages began on April 17 (Julian or calendar day 107) and ended on May 18, with deliveries peaking around the last week in April (Fig.11). There was a slight tendency to deliver the very large smolts first. For grades greater than 120 g, the average delivery date was April 26 (Jd 116). For smaller smolts, the average delivery date was May 2.

The smolt samples are ranked in Table 6 according to severity of fin erosion, with the final fin condition column being the sum of the corresponding values in the four previous columns. There was a tendency for smaller smolts to have poorer fin conditions. The regression relating fin condition to smolt size is:

$$\text{Condition} = 1.86 - 0.0078 * \text{smolt weight} \quad (p=0.005,\ R^2 = 0.17).$$

The mean conditions for 40-60, 60-80, 80-100, 100-120, and >120 g smolts were 1.80, 1.16, 1.03, 1.26 and 0.73, respectively (these values are true averages, not derived from the regression formula). Some of the 83% of the variance not accounted for

by the regression is presumably due to inter-hatchery variance. S_2 smolts were omitted from the regression as they usually had poor fin condition (mean of 2.30).

Smolt samples came from 15 different hatcheries. In Table 7 the fin condition residuals for the various hatcheries are given. A negative value indicates better than average fin condition. The sample sizes for most hatcheries are too small to permit any conclusions. It is of interest to note that fin conditions were relatively good for smolts from the recirculation hatcheries.

In Fig.12 the numbers of fish dying out of the 10 tested in the salinity challenges are plotted in relation to their mean length and fin condition. The numbers dead are also given in the "morts" column in Table 6. Mortalities marked by a single asterisk in Table 6 and Fig. 12 are from samples where the smolts were exposed to incorrect salinities first (the bath was mixed using fresh water, resulting in a salinity of 7 psu), so the smolts had to be removed while the bath was being remixed. This extra handling stress may well have contributed to the mortality. In the sample marked by a double asterisk, the smolts appeared not to have been starved prior to transit, resulting in extreme fouling of the water in the salinity challenge. The mortality marked with a triple asterisk had suffered extensive scale loss in transit prior to the salinity challenge. This factor was also significant in the sample for site 60, cage 26 of Table 6.

Figure 12 has been divided horizontally into three panels. The upper panel depicts the results for smolts with mean fin condition rating less than 1 (the lower the number, the better the fin condition). The middle panel summarizes mortalities for smolts with fin conditions between 1 and 2, and the lower panel summarizes mortalities for smolts with fin condition greater than 2. For smolts with fin conditions of less than 2, mortalities were less than 10% if samples with extensive scale loss or full stomachs were excluded. Over 60% of these smolt samples incurred no mortalities. The highest mortalities were obtained with small smolts (15-17 cm fork length) having poor fin condition. As will be shown in a later section, smolts <60 g generally experience higher mortalities immediately after transfer to sea cages.

The S_1 (smolt age of 1+) smolt fork lengths summarized for all samples (Fig.13) indicate that the average smolt size was about 19.5-20.5 cm, corresponding to 75-95 g in weight (Fig.14). Whether or not this accurately reflects mean sizes of all S_1's placed in the cages depends on whether the sampling was biased toward larger or smaller smolts. Some farmers were more reluctant to supply samples of larger smolts. The S_2 (smolt age of 2+) smolts logically averaged larger than S_1's (upper panel, Fig. 13), with a mean length of about 23 cm (ca.130 g).

Sex ratios of smolt samples were dependent upon smolt size (Table 8). For S_1 smolts, the smaller sizes of smolts were consistently about 60% males. At 19-21 cm (near average smolt size), the ratio was near 50-50, while for the largest S_1 smolts, females outnumbered males by 2 or 3 to 1. The overall proportion of males for S_1 smolts was 0.49 - not far from equality. The slightly greater number of females may be real, however, when one considers the preponderance of males in S_2 smolts (75%). As well, some hatcheries discard precocious males. The implied more rapid growth of female parr may be related to the tendency of males to become precociously sexually mature, with energy being directed to maturation as well as growth.

There was no significant difference in mortalities of male vs female smolts in the salinity challenge - about 17% for each - nor were precocious males more sensitive to high salinity.

SWIMMING SPEEDS OF SALMON IN SEA CAGES

On each visit to the farms in the survey in 1995 and 1996, the apparent swimming speed of 10 fish in each of the three study cages was usually estimated. The most striking characteristic of these distributions (Fig. 15) is that the average swimming speed for both summers is about 40 $cm \cdot s^{-1}$ (overall average of 43.9; 44.9 for the first summer, 41.6 for the second), although the average fish length in the second summer is about 50 cm, as compared to 30 cm for fish in the first summer. The means for the two summers did not differ significantly ($t=1.32$, $df=91$, $p=0.19$). It would be natural to suppose that larger fish might swim faster. A possible explanation, which will be examined later, is that the temperatures were lower when swimming speeds were measured in the second summer, because measurements were made in May-July, 1996 as compared to July-September, 1995.

As a result of larger fish size in the second summer, the relative swimming speeds (in terms of body length (bl)$\cdot s^{-1}$) are somewhat slower (Fig. 16), averaging about 0.8 bl$\cdot s^{-1}$ as compared to ca. 1.5 bl$\cdot s^{-1}$ for the first summer.

The decrease in relative swimming speed (in terms of bl$\cdot s^{-1}$) occurs as a smooth progression (Fig. 17). The curve defined by 43.9 cm$\cdot bl^{-1}$ accounts for 38% of the variance in the points. This line is the path one would expect the points to lie along if swimming speed were a constant at 43.9 cm$\cdot s^{-1}$. The fit is reasonably close, although the scatter does admit the possibility that other factors than body length may be of influence as well.

Temperature was mentioned earlier as a possible influential factor. However, temperature regimes were rising from 4.6-10.5°C during the period when measurements were performed during the second summer, yet swimming speeds were relatively constant (Fig. 18). Temperatures were also rising from 11°C to a peak of about 13°C during the first months of measurement in the first summer (late July to late August); yet again the swimming speeds in absolute terms (cm$\cdot s^{-1}$) showed no trends. In terms of bl$\cdot s^{-1}$, the swimming velocities declined during this period of rising temperature. A priori, faster swimming velocities might be expected at higher temperature. The evidence suggests that temperature regimes during the periods of swimming speed measurement had little influence on the observed temporal patterns of swimming velocities. It may be, however, that temperature in the 0-2°C range result in reduced swimming activity. It is commonly observed that at very cold temperatures, salmon tend to become inactive and remain near the bottom of the cage.

One cage of fish exhibited no swimming activity whatsoever when measured in early September 1995, apparently suspended motionless in the water column.

Two other factors considered to have possible influence on swimming velocities were cage size and current regimes in the cages. Biomass density in the cages was not considered, because it was correlated with fish size, and any effects could not be separated from fish size effects in this study.

To examine influences of cage size and current velocity on the measured swimming velocities, we calculated the swimming speed residuals for each set of measurements. (The differences between the average swimming speed for all measurements (43.9 cm$\cdot s^{-1}$) and the mean swimming speed for each cage of fish were calculated.) For example, if the average swimming speed of 10 fish in a particular cage was 36.3 cm$\cdot s^{-1}$, then the swimming speed residual is 36.3 - 43.9 = -7.6 cm$\cdot s^{-1}$.

There was no consistent influence of cage size on swimming velocity, but cage shape had a decided influence (Table 9). There was a significant tendency for fish in square cages to swim at less than average speeds. The apparent greater number of incidences of fish swimming at below average speeds in cages of surface area between 100 and 300 m^2 is due to the fact that all square cages are in this range. There was also a significant tendency for fish to swim at less than average velocities at sites where current velocities were equal to or less than 3 cm$\cdot s^{-1}$ (Table 10, 11), with fish in these cages averaging about 10 cm$\cdot s^{-1}$ less than the average for all cages combined. For cages sited in similar current regimes, fish swimming velocities in square cages always featured more negative residuals than for fish in circular cages (Table 11). More cages with current regimes >12 cm$\cdot s^{-1}$ would have been desirable in the study.

The data suggest that salmon in sea cages tend to be programmed to swim at a relatively constant velocity of the order of 40 cm$\cdot s^{-1}$ for most of their residence there. The observations should be extended to cover the period immediately after transfer to sea cages and later in the second summer - until the fish approach marketable size. In laboratory studies, swimming speed has been shown to influence appetite and growth, with an optimum velocity near 1 bl$\cdot s^{-1}$ for salmonids (see Discussion). The overall mean swimming velocity from all measurements was 1.04 bl$\cdot s^{-1}$. However, the average swimming speed for post-smolts (ca. 25-cm bl) is higher: 1.5-2.0 bl$\cdot s^{-1}$. Such high swimming velocity may contribute to the relatively low feed conversion ratios obtained for salmon early in the first summer (discussed in a later section).

FEEDING STRATEGIES ON SALMON FARMS

Boiling times varied from 0-1500 s (= 25 min) (Fig. 19, 20), and did not appear to differ significantly among cages of different sizes. Feeding times (times operators fed fish) tended to be longer than boiling times (i.e. most feeding times lie above

the dashed line of Fig. 19, along which feeding time equals boiling time). In general, the slopes of the regression lines relating feeding times to boiling times are near 1, indicating that boiling time may be used by the feeder as a cue as to how long to feed - the longer fish boil, the longer they were fed. There was, however, much variation among farms for this relationship - as evidenced by the scatter of points in Fig. 19. Due to this scatter, the regression lines are statistically significant only for large cage surface areas, those that were 150-250 m^2 (50-m plastic circles and larger steel cages), probably because this large cage size category featured the greatest range of boiling times.

In general, the larger the cage size, the longer fish were fed after boiling ceased. For the smallest wooden cages the average feeding time exceeded the boiling time by about 7 min. For the largest plastic circles, feeding time averaged about 20-25 min longer than the boiling times. This is probably due to the fact that the ration per individual fish (termed "unit" ration from here on) is less at the end of boiling in larger cages, and the feeder feels he has to feed that much longer. The effect of the greater biomass present in large cages on feeding rates will be discussed.

Typical boiling times were 3-4 min (Fig. 20) and showed no consistent pattern with time of year, probably because no observations were made during the winter months. Boiling times of fish fed medicated food (circled points in Fig. 20) were usually shorter.

Feeding times were related to cage size, averaging from 598 s (10 min) for the small wooden cages up to 1465 s (24-25 min) for the 70-m plastic circles (Fig. 21). Distribution of feeding times tended not to follow a normal (bell-shaped) curve, but were skewed to the right. A few farms fed for much longer than the majority. Feeding times for moist vs. dry diets did not appear to show any general differences (Fig. 22).

The amount of feed delivered to the cage in a single feeding was correlated with the biomass of fish in a cage (Fig. 23) - the greater the biomass, the more feed was added. With the exception of 6-8°C, the feed increment per kg increase in fish biomass tended to be higher at higher temperatures. For example, at 12-14°C (top panel in Fig. 23) the equation relating amount of feed fed to fish biomass was:

Feed = -4.4 + (.013*kg of fish biomass).

Thus, for each extra kilogram of fish biomass, the farmer, on average, fed an extra 13 g of feed (remember, these feed measures have water content subtracted, thus 13 g = 13.9 g of dry feed or 15.9 g of moist diet). In contrast, at 4-6°C (lower panel of Fig. 23) the increase in feed fed per kg increase in fish biomass was 3.6 g. This decrease in feed added per unit increase in fish biomass at lower temperatures seems logical, considering that the salmon's metabolic demands are less at lower temperatures. In Fig. 24 the slopes of the lines in Fig. 23 are plotted in relation to temperature. The vertical bars indicate the 95% confidence limits for each point. Although the relationships are weak, they suggest the amount of feed added per unit increase in kilograms of fish biomass decreases by 0.85 g per degree drop in temperature. On average 7.8 g of extra moisture-free feed is fed per kilogram increase in biomass at 10°C, as compared to 3.6 g at 5°C.

It should be noted that these observations are not related to the total amount of feed fed over an extended period of time, but are only typical feed levels at a single feeding. It is also assumed that the feeding strategy was not influenced by the presence of observers.

Finally, we define feeding rate as the grams of moisture-free feed fed at a single feeding per kilogram of fish biomass per 100 s. This is a measure of how fast food is delivered to the cage on a unit weight basis. It is apparent that salmon farmers generally do not adapt feeding strategies to the increasing biomass of fish in a cage (Fig. 25). For example, the average weight of fish in a cage may increase from-, say, a 100g smolt to a 8000-g pre-market fish - an increase of 80-fold. Thus, other things being constant, the total biomass will increase 80-fold. If the feeding rate were to be kept constant, then the feed would have to be added 80 times as fast for the pre-market fish. (Note this does not imply anything about the amount of feed fed, only how fast it is delivered to the fish.) In fact, feeding rate decreases as biomass increases (Fig. 25). The curve drawn in Fig. 25 is calculated, based on the assumption that the feeding rate is inversely proportional to the fish biomass in a cage (for example, if the biomass doubles, the feeding rate is halved). It is the calculated line of best fit for this particular model. It fits the trend fairly well, although the scatter among farms is large. The line does not fit the data well for biomasses greater than

predicted by the model. Most of these high biomass levels are in the large plastic circles. Interestingly, the use of blowers did not lead to an increase in the feeding rate in these large cages. Many points for the steel cages lie above the line, indicating that some farmers are adjusting their feeding rates to some degree as fish grow.

The above observations raise some interesting questions. Are farmers feeding small fish too fast or large fish too slowly? Also, though the biomass may increase 80-fold, the fish may not be able to ingest food 80 times as fast - the fish numbers do not increase and the mouth size and swimming speeds certainly do not increase 80-fold. At any rate, the current feeding strategy seems to be to add feed to the cage at a constant rate, and adjust for increasing biomass by increasing the duration of the feeding periods.

A critical question is: does feeding rate affect growth rates and/or feed conversion ratios? The question will be addressed in a later section; although the data may provide an answer only for low biomass (i.e. in the first summer), because few feeding rates for large biomasses exceeded values predicted by the model.

The surface area of the cage that was fed during a meal is shown in Fig. 26 for various sized cages. For small, wooden, octagonal cages, over 80% of the cage surface was fed in over 50% of the observed feedings (8 of 15). On average, 72% of the cage surface was fed. For medium sized cages (larger wooden and steel), the curve peaked at 60-70% of the surface receiving feed, and was apparently nearly normally distributed on either side of the peak. On average, 61% of the cage surface received feed. For large cages (50-m plastic circles and larger steel cages), the distribution was similar to that for feedings of medium sized cages, with the average again being 61%. For "extra" large (70-m plastic circles), the most frequent area receiving feed was 40-50%, with the average being 56%. There is a suggested trend toward feeding a smaller percentage of the cage surface area with progressively larger cages. Interestingly, the use of blowers did not lead to an increase in the observed cage surface area receiving feed. Perhaps other factors come into play; for example, it may be difficult to assess accurately how close the feed is being placed to the far side of these larger cages.

PELLET SIZE RELATIONSHIPS

It is important to remember when feeding fish that fish feed by the pellet, not by the kilogram. As fish grow, farmers logically shift to larger pellet sizes (Fig. 27). This means that if the feeding rate remains constant (in terms of grams of feed/kg of fish biomass/100 s), the number of pellets per feeding and per unit time decrease dramatically as the fish grow. Figures 28-30 illustrate the general relationship between numbers of pellets per kilogram of feed and pellet size (pellet weights provided courtesy of W. Robertson, Connors Bros. Ltd.). Small fish fed the smaller pellet grades receive many more pellets per unit time at a constant feeding rate. The relationship is rough, because pellet length can vary among batches. Also, moist pellets particularly are easily broken into smaller pieces. If pellet length were constant and crumbling did not occur, the number of pellets per unit weight should be proportional to the square of the pellet diameter. Therefore if plotted on a semilogarithmic scale, one decade change in pellet width (i.e. from 1-10 mm, or 0.1-1.0 in.) should cover a span of two log units for numbers of pellets. This is roughly the case, as shown in Fig. 29 and 30.

The average number of pellets fed per fish in a single feeding (Fig. 31-34) is highly variable, but tends to decline rapidly as the fish increase in size from 100-500 g - as expected from the above discussion. In this size range the number of pellets fed per fish may vary from 2-3 to over 80, but typically in the range of 16-40. In the extra large cages (Fig. 34) larger numbers of dry food pellets were usually fed per fish than were moist pellets.

At average fish weights greater than 500 g, the number of pellets per fish varied from 1-28. Again in the extra large cages, greater numbers of dry pellets were fed per fish than were moist pellets; simply there are more dry pellets per unit weight. It must be emphasized that these data are for single feedings and should not be extended to long-term relationships.

The fewer number of pellets may lead to increased competition and more variable growth. If, for example, only 2 pellets are fed per fish, then the dominant fish may get 4 or 5 and the subordinate ones none.

Moist pellets were fed more frequently than dry at first feeding (25 moist vs 5 dry for fish of 100-300 g mean weight). At mean weights greater than 300 g, the distribution between moist and dry feeds was more evenly split: 47 moist vs 39 dry.

With moist feeds, 1/8-in. pellets were not fed to fish averaging more than 300 g, with 1/4-in. being prevalent in the 500- to 700-g size class (Fig. 27). Pellet sizes of 5/16-1/2 in. were used for fish weights of 700-2300 g, with 1/2 in. being prevalent in the 2100-2300 size range.

With dry feeds, a 3.0- to 3.5-mm pellet size was most used for 100 - to 300-g fish, grading into 5 mm by the time the fish were 300-500 grams. At weights greater than 1 kg, 7- to 8-mm and 9- to 10-mm pellets were both used. Our observations did not extend to fish larger than 2900 g on average.

SPECIFIC GROWTH RATES

Instantaneous specific growth rate expresses the rate of growth as percent per day averaged over a specified period of time. The form usually used is:

$$G = [(\ln W_t - \ln W_0)/t]*100,$$

where $\ln W_t$ is the natural logarithm of the weight after time = t(usually days), $\ln W_0$ is the natural log of the initial weight, t is the time period over which the estimate of growth rate is desired, and G is the specific growth rate. If one wishes to use the formula to forecast a projected weight, assuming a certain value of G over a certain time period with a given initial weight; then the formula can be rearranged to give W_t as follows:

$$\ln W_t = (G/100)t + \ln W_0.$$

Size in first summer

An initial model of post-smolt growth rates for the first summer predicted that small smolts should overtake larger smolts in late September or early October - which did not agree with the experience of many farmers. In view of this contrast, the first summer growth rates of the 60 cages of fish in the survey were examined more fully using two additional models.

Two factors (other than husbandry-related factors) which influence the growth rate of salmon in the first summer are initial smolt size, and time when the fish in the cage are measured. A third factor - time when the smolts were placed in the cages - appeared to be significant, but, as will be explained, is largely related to the delivery patterns of the hatcheries and so is misleading if taken at face value. From scanning the raw data it was obvious that smaller smolts have higher specific growth rates. The predictions, from a model of how much higher, are a function of the coefficients generated in the model. In some cases the small smolts obviously caught up to the large. For example, at one site we monitored three cages containing 99-g, 77-g and 52-g smolts. By Julian day 256 (mid-September), the 99-g smolts weighed 413 g on average, the 77-g smolts 429 g, and the 52-g smolts 419 g - not much difference. At another farm, a cage of 49-g smolts averaged 422 g by Julian day 250, while a cage of 98-g smolts averaged 449 g. Smolt quality is probably also a factor. Certainly these cases influence the results of fitting models to the data. The question is: what is the typical - or average - situation? This is what a model should tell us.

Also influencing the model in the interim report was an incorrect data point. We had been informed that one of the cages in the survey contained 190-g S_2 smolts. The growth rates obtained from this cage were very low. It was later determined that this cage received smolts of variable sizes with uncertain average weight, so this cage was dropped from subsequent models.

The actual fish weights measured at the 20 farms are entered in Table 12, and the corresponding specific growth rates (G) in Table 13. These are the raw data from which the models were produced. By scanning Table 13, it may be seen that there is a trend, for any smolt weight class, for increasing G as the summer progresses. This is presumably due to rising temperature over this time period. The trend in decreasing specific growth rate with increasing smolt size for a given time period is also apparent. The models that are generated are simply ways of estimating the average trends for these relationships. Keep in mind that specific growth rate is like compound interest on an investment. A relatively small change compounded over a fairly long time can result in relatively large differences in the final weight.

Three models were generated, and are listed below:

$$G = -0.92033 + 0.007533S + 0.07431t_f - 0.0000274S^2 - 0.0001365t_f^2 - 0.00007787t_f*S + 0.01033t_i \quad (1)$$

where G is the specific growth rate, S is initial smolt size, t_f is the time (Julian days) when the cage of fish was measured, and t_i is the time when the smolts went in the water. This is a complicated power function derived by a computer "monte carlo" program, but first of all look at the signs of the coefficients. Those for smolt size (+0.007533), time when smolts went in the water (+0.01033), and time when size was measured (+0.07431) are positive, indicating that an increase in smolt size or time will increase the growth rate. The three negative coefficients are for the square of smolt size (-0.0000274), the square of time of measurement (-0.0001365) and the interaction between smolt size and time of measurement (-0.00007787). An increase in these factors will decrease the growth rate estimate. Because the squared terms are associated with negative coefficients, these terms will outweigh the positive terms when S and t_f are sufficiently large.

The second model is somewhat simpler, relating the logarithm of G to smolt size, smolt entry time, and measurement time. Only linear relationships and functions with significant coefficients were used.

$$\log G = -0.001567S + 0.001975t_f + 0.003441t_i - 0.6908 \quad (2)$$

Again t_f and t_i have positive coefficients, but that for smolt size is now negative. Note that only factors that account for significant amounts of variance are included in all these models. Although smolt entry time (t_i) is a statistically significant factor in these models, its biological significance is spurious, because hatcheries tended to ship smaller smolts later in the season. Since smaller smolts have higher growth rates, smolt entry time seemed to have a significant influence on growth rate. Smolt entry time was not independent of smolt size (see previous section).

The third model excludes the data for the 215-g smolts. This point is an outlier, with no other data points near it. As a result, this data point had a disproportionate influence on the determination of the coefficients.

$$\log G = -0.002112S + 0.002036t_f + 0.003722t_i - 0.6953 \quad (3)$$

This model is similar to model (2) in terms of size and sign of the coefficients. All three models account for about the same amount of variance in the data: 60-70%, and the patterns of residuals (differences between real and estimated values) are similar, with no particular bias with change in smolt size (Fig. 35-37) or time.

We now address the question of what each model predicts in terms of growth rate and weight gain for different sized smolts (S) and for different times in the first summer (t_f). First we compare predicted growth rates (G) for the 3 models.

Model 1

Size	May 31	June 30	July 31	Aug 31	Sept 17
40	0.092	0.868	1.412	1.694	1.737
50	0.074	0.827	1.347	1.605	1.635
60	0.062	0.792	1.288	1.521	1.538
70	0.056	0.762	1.234	1.443	1.446
80	0.055	0.737	1.185	1.370	1.360
90	0.059	0.718	1.142	1.303	1.280
100	0.069	0.705	1.104	1.241	1.205
110	0.084	0.697	1.072	1.185	1.135
120	0.105	0.694	1.045	1.134	1.071
130	0.131	0.697	1.024	1.089	1.013
140	0.163	0.706	1.009	1.049	0.960

The squared terms in this model result in some non-linear results. For example, due to the negative interaction between smolt size and time, the growth rate of small smolts increases in September, but that of large smolts decreases. This is not realistic, and indicates some problems with this model.

Model 2

Size	May 31	June 30	July 31	Aug 31	Sept 17
40	0.959	1.099	1.265	1.457	1.574
50	0.925	1.060	1.220	1.405	1.518
60	0.892	1.022	1.177	1.356	1.464
70	0.860	0.986	1.136	1.308	1.412
80	0.830	0.951	1.095	1.261	1.362
90	0.800	0.918	1.056	1.216	1.314
100	0.772	0.885	1.019	1.173	1.268
110	0.745	0.854	0.983	1.132	1.223
120	0.718	0.823	0.948	1.092	1.179
130	0.693	0.794	0.914	1.053	1.138
140	0.668	0.766	0.882	1.016	1.097

The results of the second model differ from those of model 1 in several respects: the predictions are linear with no trend reversals, it predicts much higher growth rates in May, and the differences in G for large and small smolts in September are not as great. In general it is a more conservative model.

Model 3					
Size	May 31	June 30	July 31	Aug 31	Sept 17
40	1.001	1.152	1.332	1.540	1.668
50	0.953	1.099	1.269	1.467	1.589
60	0.908	1.045	1.209	1.398	1.514
70	0.865	0.996	1.151	1.331	1.442
80	0.824	0.948	1.100	1.268	1.373
90	0.785	0.903	1.044	1.208	1.308
100	0.748	0.860	0.995	1.151	1.331
110	0.712	0.820	0.948	1.096	1.187
120	0.678	0.781	0.903	1.044	1.131
130	0.646	0.744	0.860	0.994	1.077
140	0.615	0.708	0.820	0.947	1.026

This model is similar to Model 2 for May-June, but is in between models 1 and 2 in August-September. We will next examine what weights the predicted growth rates yield at different times in the first summer. The number in brackets after each date is the Julian day.

Model 1 Weights					
Size	May 31 (151)	June 30 (181)	July 31 (212)	Aug 31 (243)	Sept 17 (260)
40	40.9	63.9	132.9	285.4	403.2
50	50.9	78.2	157.2	321.7	439.8
60	60.9	92.0	179.3	350.3	463.9
70	70.9	105.6	199.7	373.3	479.2
80	81.1	119.1	219.0	392.1	488.4
90	91.3	132.7	237.6	434.8	497.9
100	101.7	146.3	255.6	421.9	496.5
110	112.2	160.3	273.6	434.8	497.9
120	123.1	174.6	291.8	447.2	498.8
130	134.2	189.5	310.5	459.6	499.9
140	145.6	205.0	329.9	472.6	501.6

According to this model, 60- to 90-g smolts put on about 400 g up to Sept.17 (the last date for which data were accumulated), whereas 140-g smolts grow by 360 g.

Model 2 Weights					
Size	May 31	June 30	July 31	Aug 31	Sept 17
40	50.4	72.4	117.2	216.8	324.5
50	62.4	88.6	141.0	255.1	376.5
60	74.3	104.2	163.2	289.2	420.5
70	86.0	119.2	183.8	319.2	457.8
80	97.6	133.7	202.9	345.4	489.6
90	109.0	147.8	220.8	368.8	516.7
100	120.4	161.3	237.8	389.9	540.0
110	131.5	174.4	253.7	409.0	559.5
120	142.6	187.2	268.6	425.9	575.7
130	153.5	199.6	282.7	441.0	590.6
140	164.3	211.7	296.3	455.0	602.2

Model 2 yields heavier fish by the end of May than does model 1. May and June estimates are interpolations for a period when no actual measurements were made; there is no way of telling which model is most accurate for these months. The September weights are where the models diverge most. Model 2 predicts heavier weights for larger smolts (>80 g) and lighter weights for small smolts. For 80-g smolts, the predictions are about the same. This is to be expected, since an 80-g smolt is average for the study, and involves least extrapolation. On average a 40-g smolt will probably attain 320-400 g by mid-September, while a 140-g smolt will attain 500-600 g.

Model 3 Weights					
Size	May 31	June 30	July 31	Aug 31	Sept 17
40	50.9	74.5	129.5	238.8	367.7
50	62.8	90.5	147.0	274.2	413.8
60	74.6	105.5	167.7	303.7	449.4
70	86.2	119.9	186.2	327.8	476.4
80	97.5	133.5	203.8	348.2	496.8
90	108.6	146.6	218.6	365.4	512.6
100	119.7	159.1	233.0	380.1	524.4
110	130.5	171.3	246.2	392.2	533.4
120	141.2	183.0	258.5	402.8	540.1
130	151.8	194.3	270.0	411.8	544.5
140	162.3	205.2	281.1	420.0	548.0

As mentioned before, model 3 differs from model 2 by the omission of a data point for 215-g smolts. The weights predicted for Sept. 17 are intermediate between those of models 1 and 2. Small smolts attain heavier weights than in model 2, but less than in model 1. We tend to favor model 3 as it

fits the data for 40- to 140-g smolts a bit better than does model 2 (R^2 = 0.65 vs 0.60 for model 2). It also seems to reflect actual weights fairly well for July to September. According to this model, most of the gain from increasing smolt size is in the 40-80 g range. Above 100 g, the benefit is much less. It should be remembered that these weights are estimates of survey averages, and that cages of smolts that do particularly well will be larger than values given in these tables.

Size early in second summer

The fish in each of the surveyed cages were measured a second time in May to July of the second summer (1996). For each cage, the average specific growth rate (G) from the time the smolts were placed in the cage until this second measurement was calculated - a period of time spanning about 430 d.

Since the growth interval spanned the low temperature period, and since the fish were of greater average weight, the G values are generally lower for this second measurement (Fig. 38), ranging from 0.5-1.0% per day.

As with the first summer's data, the influence of various variables on G was investigated by multiple regression. Initial smolt size was again the single most influential variable, accounting for 60% of the variance. Time of smolt entry was again significant, accounting for 8% of the variance, but as explained previously, this influence is due mainly to the fact that hatcheries tended to ship out small smolts last. As a result of this spurious relationship, the only variable used to calculate expected growth rates is smolt size. The calculated regression is: logG = -0.04732 - 0.0012S (G = specific growth rate, S = initial smolt size). Table 14 shows expected specific growth rates and weights for the first 430 days after smolt entry for various sized smolts.

The value of increasing smolt size declines at larger smolt sizes. For example, a 90-g smolt should be about 550 g heavier than a 40-g smolt at 430 d post-entry, while a 140-g smolt would only gain an additional 100 g on average.

Correlation between first and second summer growth rates

We will now consider whether first summer growth rates are indicative of subsequent growth performance, e.g. to 430 d post-entry. The approach is to correlate the growth rate residuals for the two summers. As a reminder, a growth rate residual for a cage is the difference between the average growth rate for the fish in that cage and the industry average for the particular smolt and time characteristics of that cage. For example, if the average growth rate for a 50-g smolt over the first 430 d is 0.781 (cf. Table 14) and the average for a particular cage of 50-g smolts is 0.703, then the residual for that cage is 0.078. In this case, the industry average is determined from the growth rate models presented in the previous section. To put the question another way; if a cage exhibits above average growth in the first summer, is it likely to continue to have above average growth into the second summer? - and similarly for cages with below average growth in the first summer. We addressed this question first by calculating the regression equation correlating first summer growth residuals to second summer growth residuals (Fig. 39, 40). For both specific growth models 2 and 3 the correlations are statistically significant, but explain only about 15-20% of the variance. In other words, a lot of other factors can change the growth performance between the first and second summers.

There are two other points of interest in Fig. 39 and 40. First, there is more scatter in growth residuals in the first summer than in the second - the points being clustered more closely along the horizontal axis than the vertical. In other words, there was less variability in growth rates among cages in the second summer than in the first. This is partly due to the fact that measurements of fish size in the second summer were concentrated into a shorter time period, so that time of measurement was not a factor.

The second point of interest is that most points fall in the upper right and lower left quadrants. The growth performance in the first and second summers was in general agreement - this is simply another way of illustrating the significance of the correlation. There are relatively few points in the lower right quadrant - if the fish growth in a cage was below average the first summer, it was not usually above average the second.

The growth residuals analyzed in these sections will be used in subsequent sections to evaluate the influence of environmental and husbandry variables on growth performance.

Environmental variables and specific growth rate residuals

The only environmental variables that approached statistical significance as to effects on specific growth rate variance among surveyed farms were water current and temperature. This is not to say that other variables are not influential, but in this survey, husbandry variables tended to override the environmental influences. Controlled experiments would probably demonstrate the importance of environmental variables. Temperature certainly affects fish growth, but inter-farm differences in temperature degree-days were not very great. A temperature effect on growth rate could be detected for the first summer, where differences in degree-days among farms accounted for about 11% of the variance in specific growth rate residuals (G residuals after influence of smolt size removed) among cages. If the data is smoothed somewhat by averaging cage residuals for each farm, temperature accounts for 17% of the residual variance (Fig. 41). If the two Grand Manan sites are removed from the regression, the R^2 increases to 38%. The Grand Manan sites performed better than expected for the first summer, possibly due to less net fouling or lower sea louse densities. No significant temperature influence could be demonstrated for the second summer growth rates because warmer summer sites were colder winter sites, so there was some temperature composition over a full year.

Specific growth rate residuals for the first summer showed a similar marginally significant ($p = 0.08$) relationship with water current (Fig. 42A), accounting for 16% of the residual variance. The relationship between growth rate residuals through to June of the second summer and water current differs from that for the first summer (Fig. 42B). There is a suggestion of a parabolic relationship (depending upon a single point), with growth rate residuals higher at intermediate current velocities. Although speculative, the data suggest that optimal currents for growth may increase with increasing fish size, up to a point.

Referring back to the clusters defined by the discriminant function analysis of environmental variables, we find that there are no significant differences in specific growth residuals among the clusters, although cluster 2, with the lowest water currents had 8 of 10 residuals positive for the first summer. Cluster 1, with the fastest currents, had the highest mean residual through to the second summer.

MORTALITIES ON THE MONITORED SALMON FARMS

Fourteen of the 20 farms provided complete mortality records from smolt entry to harvest. In addition, partial records (for the first summer) were obtained for three other farms, two of which had to be dropped because of mixing with fish from other cages.

The overall average mortalities due to various factors are summarized in Table 15. A total of 646,721 salmon were followed from smolt entry. Of these 87,475 (ca. 12%) were lost from the study due to transfer to unmonitored cages, leaving 559,246 smolts monitored until harvest. Of these 475,434 (85%) were recorded as harvested. Total recorded mortalities amounted to 72,281, or 12.9% of the number monitored. An additional 11,531 fish (2.1%), recorded as placed in cages, were unaccounted for when final tallies were made after harvest. Thus, for an average of 10,000 fish, 8500 would be harvested, 1290 would die of various causes, and 210 would be unaccounted.

Of the average total mortality of 12.9%, 3.0% were attributable to disease, with "cold-water" bacteria and bacterial kidney disease (BKD)-infectious salmonid anemia (ISA) taking the largest toll. Fish in three of the monitored cages had become infected with ISA in late summer of 1996. Smolt entry losses accounted for nearly another 3%. Reported losses due to seal predation amounted to slightly over 2%, and losses attributed to bird "picks" another 0.14%. Mortalities due to unspecified causes amounted to 4.89%.

The percent of fish harvested in the 38 cages for which complete records were obtained ranged from 70-100% (Fig. 43).

Most of the unaccounted fish percentages were in the range of -2% (deficit) to +2% (surplus), which may be indicative of the combined error in estimates of initial smolt numbers and reporting of mortalities. In a couple of cases the deficit/surplus ran as high as 17-18% (Fig. 44).

Total recorded mortalities were most frequently around 8% (Fig. 45), with two cages having only 2% recorded mortalities. Cages

experiencing 20% or more mortalities contained fish which experienced seal predation (four cages in all) or epidemics of disease (three cages). The fish remaining from the cage suffering more than 50% loss due to seal predation were transferred subsequently to an unmonitored cage containing other fish, so the total harvest was unavailable.

Losses due to transfer to seawater amounted to about 3% on average, but smolts in the 40- to 60-g range suffered losses of about 6% on average - as compared to 1.5-2% for larger smolts (Fig. 46). These differences in initial losses are not reflected in percentages harvested (Fig. 47). Subsequent losses (mortality and unaccounted) tended to swamp out these initial losses by harvest time. However, these initial losses do put a cap on the maximal harvest yields, since all harvests greater than 95% (six cages) were from cages of larger smolts.

The "unspecified" mortalities represent the single largest source of mortality on the average. Catastrophic mortalities, through disease or seal attacks, were infrequent in this study (seven cages). The "unspecified" mortalities show a cyclic pattern (Fig. 48), averaging about 0.25% per month for the first summer, dropping to about 0.12% per month in the winter, and rising again to 0.2-0.25% in the second summer, then falling once more during the second winter. The increase in unspecified mortality toward the end of the second winter is probably associated with handling during harvesting, and perhaps with mortality of sexually mature fish. The data suggest that these mortalities may be temperature related. Many stresses, for example sea lice, competition for food, aggressive behavior, and marginal disease occurrences are probably all more prevalent in the warmer months. A "slink" (salmon in poor condition) that is not feeding would be more apt to die during higher temperatures when metabolic demands are higher.

Stocking density may have a slight but statistically significant influence on unspecified mortalities (Table 16). Cages that were initially "double" stocked or higher had an average unspecified mortality of 5.2% (n=17), as compared to 4.0% (n=23) for cages initially single stocked (t-test, unequal sample sizes: t=1.78, p=0.04). Cage size had no discernable influence on these unspecified mortalities, nor could any significant differences associated with hatchery source be identified - possibly partly because of insufficient sample sizes for most hatcheries.

SEXUAL MATURATION OF FARMED SALMON

Sexual maturation of farmed salmon represents a financial loss to the farmer, because the market value is minimal due to loss of condition and flesh quality.

The maturity data obtained from fish shipped to processing plants from the surveyed farms are summarized in Table 17. The data must be viewed with a certain degree of skepticism, because the various farmers dealt with grilse in different ways. One farm culled all mature fish and kept counts of these in their records; hence no mature fish were observed in processed fish from this farm. We have calculated the percent mature fish in each of the three cages monitored at this farm, and used these percentages to produce a "probable" number of matures that would have been sampled had they not been culled. At least one other farm retained most of the matures in the cages until the end of harvesting, when they were sent to the processing plant. In this case, the numbers of mature fish sampled depended upon what lots of fish were sampled. Most farmers indicated that mature fish were included in the shipments as they were encountered during slaughter. Some of the variability in percentages of mature fish recorded for the various smolt size classes of Table 17 results from different ways of dealing with matures, and some is probably due to sampling deficiencies. Reliable sex ratios require large sample sizes.

A total of 7011 fish were examined at the processing plants from a total of 142 trips to the plants - on average between 2 and 3 samples from each cage in the survey.

Female fish outnumbered males in the samples (54.6% of all fish being females). Females also outnumbered males in the smolt samples analyzed at the beginning of the survey (51%). For all smolt sizes the percent of males in the smolt samples usually was higher than in the processed samples - particularly noticeable in the smaller smolt classes. It may be that some females were incorrectly sexed in the smaller smolts. There may be some differential mortality in the cages as well. Both data sets show increasing percentages of females with increasing S1 smolt size, and a preponderance of males in the S2's.

Overall, 8.3% of males matured sexually prior to harvest, as compared to 0.8% of females.

The condition factors (cf) of mature fish were compared to those of non-mature fish from the same sample (Fig. 49, 50). The cf differential used in these figures is simply the difference between the cf of mature and non-mature fish of the same sex. For example, if non-mature males had a cf of 1.00, and a mature male had one of 0.80, the mature fish cf differential would be -0.20. For calculation of cf, see Appendix 1.

The figures show that mature fish cf's begin to fall below those of non-mature fish in early October. Females do not lose condition to the extent of males - probably due to the larger volume of ovaries.

One cage of fish was not harvested until September 1997, at which time the previously matured fish had regained condition, and actually had a higher cf than fish that had not matured.

DEFORMITIES IN MARKETED SALMON

Five types of deformity were recognized in batches of fish sampled at processing plants: a lower jaw deformity where the lower jaw is bent downward to varying degrees; an upper jaw deformity where the upper jaw is shortened, giving the fish a "bulldog" appearance; spinal curvature (scoliosis or lordosis); compressed spinal cord, giving the fish a stubby appearance; and a tail deformity, which we term "hole in the tail", wherein some medial fin rays appear to be missing.

Out of 7050 fish inspected at processing plants, a total of 314 had one or more of the above deformities (Table 18). The deformed lower jaw was most frequently encountered, with 208 fish (3% of all fish inspected). This total would have been considerably higher if we had counted marginal cases with only slight deformity of the jaw tip. Instead, we counted only markedly deformed fish.

With the exception of the abnormal tails, the various deformities may have a common cause, since the incidence of the lower jaw deformity from various hatcheries is significantly correlated with the others:

$(I_O + 0.003 + 0.313\ I_{lj};\ R^2 = 0.73,\ P = 0.00009)$,

where I_O is the incidence of other deformities, and I_{lj} is the incidence of lower jaw deformity. All deformities, except the abnormal tails, result from some sort of skeletal deformity. Insufficient oxygen supply during critical stages of skeletal formation has been shown to produce some of these deformities (e.g. Alderdice et al. 1958). Heavy metal and some pesticides may also act as teratogens (von Westernhagen 1988). Whether this is the case here is not known. Compressed spinal cord has recently been suggested to be possibly due to infection (Kvellestad et al. 2000) after transfer to cages.

By comparing weights of deformed fish with weights of normal fish from the same sample, we were able to estimate the influence of each deformity on fish size. Fish with the deformed lower jaw averaged 0.64 kg less in weight than normal fish. So for a "typical" cage of 10,000 fish, about 200 fish would have this deformity, amounting to a loss of about 140 kg - in the order of a $1000 loss. On top of this loss would be possible losses associated with downgrading due to appearance. Upper jaw deformity seemed to have a lesser effect on growth, resulting in only a reduction of 0.18 kg.

Spinal deformities have a greater effect on growth; fish with these deformities averaged 1.38 kg less than normal fish from the same batch. Actually, these fish may be a total loss due to the extreme nature of the deformity.

Combining effects of all deformities, a "typical" cage of 10,000 fish would lose about 190 kg of flesh. However, since distribution of deformities is not even among cages, the typical cage does not occur very often; numbers of deformities will usually be much less and occasionally much greater than average, possibly due to hatchery influence on incidence of deformities.

WEIGHT LOSS DUE TO GUTTING OF FISH

It is sometimes useful to convert weights obtained for gutted fish at processing plants to ungutted weights (eg. for FCR and growth rate estimates). For 15 samples of fish for which we weighed fish to be processed prior to gutting, mean gutted weights were provided by the farmer (Table 19). Since we weighed only 50 fish from only one of the several tanks of fish to be processed in a given batch, one might expect considerable variability in results. However, averaging data for all 15 samples should provide a reasonable approximation. The

mean loss due to gutting was 12.6% with a standard error of 1.2%, so the loss should fall between 10.2 and 15% 95% of the time.

FEED RATIONS, GROWTH AND CONVERSION EFFICIENCY

Analyses of rations and feed conversions will deal with three periods, corresponding to points where size estimates were made of fish in the surveyed cages. The first period extends from smolt introduction to when sizes were estimated during the first summer (July to September 1995). The second period extends from smolt entry to the second round of weight estimates (end of June 1996), and the third covers the entire growth cycle from smolt entry to harvest. As is the case with most aspects of this study, the strategy is to establish the norm for all farms in the survey, and see if any conclusions can be drawn as to why certain farms' performance falls above or below the norm (or average performance).

To normalize some of the methodology, feed weights have been converted to moisture-free weights, assuming that moist diets are 22% water and dry diets are 7% water. This permits combining data for moist and dry diets. If it is desired to convert any weights back to uncorrected values, divide the moisture-free weight by 0.78 for moist diets, or by 0.93 for dry diets.

Figures 51 and 52 show the general pattern of feed usage over the growth cycle. This pattern is obviously affected by ambient temperature and fish size. Figure 51 shows the monthly percentages of the total feed ration averaged over 38 cages for which complete feed records were available. Feed rations peak in October for the first summer and in August of the second summer. The decline in amounts fed after August of the second summer is due to beginning of harvesting and preliminary fasting. About 25% of the total ration was fed in the first year (May-December). Nearly 15% of the total ration is fed in August of the second year (1996), and with some farms this exceeded 20%. The vertical bars indicate the 95% confidence limits for each month. For example, for August 1996, 95% of the cages should feed between 13 and 17 % of the total ration.

The upper line in Fig. 51 reflects the harvest pattern, with cages dropping out as they are emptied of fish.

Moist feed usage exceeded that of dry feed through most of the first summer (Fig. 52), with dry diets surpassing moist in November. The number of cages fed moist diet declined steadily from May 1995 until January 1996 as farms shifted from moist to dry at varying times through the first year (upper graph, Fig. 52). The number of cages fed moist feed rose again in May 1996, as some farmers used dry feeds only during the winter months. At first glance there would appear to be some discrepancy between the cages indicated as using dry diet during the second summer and the relative volumes of dry and moist feed fed in the second year. This is explained by the combined use of both feed types in many cages.

The total weight of feed used amounted to 865 MT of moist and 2464 MT of dry, for a total of 3328 MT. If we assume an average feed conversion ratio of 1.5 (which, as we shall see, is near the true average), then this feed volume should have produced about 2219 MT of salmon (fresh, undressed).

Before going into further discussion of food conversion ratios (FCRs), it should be noted that there are two ways to calculate FCR. One way is to divide the total weight of feed added to a cage by the total harvested weight of salmon from the cage. This method does not account for biomass lost through mortality. This method was used to calculate the FCRs of Fig. 53. For the subsequent analyses another method was used where each monthly ration for each cage was divided by the average number of fish present for the month. This provides a monthly unit ration (i.e. ration per fish). For each cage these monthly unit rations can be summed to provide a total unit ration, expressed as grams of feed per fish. If this value is divided by the average harvest weight, then another estimate of FCR is obtained, which I term the total unit FCR. This method was used to compare cages and farms because variations in mortalities among farms were eliminated.

The average FCR calculated for 36 cages was 1.52 (Fig. 53). If it is desired to put moisture back into the calculation, this corresponds to 1.52/0.93 = 1.64 for dry diets, or 1.52/0.78 = 1.91 for moist diets.

The two cages with FCR greater than 2 in Fig. 53 had very large numbers of pollock in them, which probably decreased the efficiency. Since some pollock occurred in many other cages, and numbers of these are unknown, this aspect is an uncontrolled

variable influencing FCR, which may mask other husbandry-related factors.

No significant differences were found in FCR among various smolt size classes. A mean FCR of 1.61 was obtained for cages fed moist diet, as compared to 1.47 for cages receiving dry diet - the difference was not quite significantly different. However, the two cages with high pollock densities were in the moist diet category. If these two cages are removed from the analysis, the average FCRs are virtually identical. Nor were significant differences due to cage size or food source obtained, although the sample size was small for many food sources. It should be noted here that a more thorough analysis of feeding efficiency, which is presented later, does indicate an effect of cage size.

Unit FCRs for the first summer

Making meaningful direct comparisons of unit FCRs among cages for the first summer was impossible - probably so many things are changing over a short period of time (e.g. feeding responses of smolts, ambient temperature). The problem was compounded by the fact that it took over 3 mo to measure weights in all the cages in the survey. The only significant relationship obtained was a decrease in unit FCR with time (Fig. 54). Here the unit FCR is plotted against the median date for the time period over which the FCR was calculated (halfway between smolt entry and weight measurement). The regression line accounts for 13% of the variance among cages. Thus the feeding efficiency appeared to improve over the course of the summer - possibly due to the factors mentioned in the first sentence of this paragraph.

Because the unit FCR in the first summer was time-dependent, this influence of time had to be factored out so that comparisons could be made among surveyed cages by using the so-called unit FCR residuals for each cage. These residuals are obtained by determining the vertical distance of each point (each point representing a cage) in Fig. 54 from the calculated line. The process is indicated for one point in the figure. Points lying below the line have negative residuals, and represent cages having better feeding efficiency than the survey average as indicated by the line. Points lying above the line (with positive residuals) had poorer efficiency than average. Although the relationship in Fig. 54 is weak statistically, it was considered necessary to correct for the temporal effect, which is probably real. The great variability in residuals from the line indicates that other factors of significance are involved. A good fit would merely indicate great uniformity among farms with regard to other variables.

Ideally, one wishes to have high growth rate, combined with a low FCR (= high conversion efficiency). Therefore the unit FCR residuals for the first summer were plotted against the specific growth rate residuals (growth model 3) (residuals were used to subtract out the influence of smolt size) (Fig. 55). A positive specific growth residual for a given cage means that the fish in that cage had an above average growth rate, correcting for intrinsic differences in growth rates among smolts of different sizes. Cages falling in the lower right quadrant of Fig. 55 have above average growth rates and below average unit FCRs for the first summer. Cages in the upper right quadrant had above average growth, but higher than expected unit FCR as well. Cages in the lower left quadrant had below average growth, but a low FCR, while those in the upper left quadrant had low growth and high FCR.

Not surprisingly, ration did affect growth rate; the farms feeding the highest rations through the first summer generally had the highest specific growth rates (Fig. 56). To show this, the average unit ration for various smolt size classes (40-60, 60-80, 80-100, 100-120 and 120-140 g) was calculated (Table 20). Then the unit ration for each cage was subtracted from the average for the appropriate size of smolt. This difference provides a unit ration residual, which indicates whether that cage received more or less than average ration for the first summer (to the end of October). For example, a unit ration residual of +200 for a particular cage means that that cage received 200 g more of moisture-free feed per fish than did the average cage in that smolt size category.

Unit ration has a highly significant influence on specific growth rate, accounting for almost a third of the variability in growth rates remaining after the effect of smolt size is removed. The line in Fig. 56 indicates that, on average, an increase in unit ration of 100 g per fish from May to October resulted in an increase in specific growth rate of 0.03% per day. The position of a cage in relation to the regression line of Fig. 56 provides an indication of the relative food conversion efficiency. If a point lies above the line in Fig. 56, then the growth of fish in that cage was greater than expected

for the appropriate ration level, and one would expect that cage to have a better (=lower) than average unit FCR. And, in fact, the unit FCR residuals are significantly correlated with the residuals of the points in Fig. 56 from the regression line. This relationship will not be shown, because second order residuals are a bit hard to visualize.

The unit ration (grams per fish) from smolt entry until the end of October varied from 364-1818 (Table 21). The average unit ration did not seem to vary for smolts from 40-100 g - averaging about 970 g per fish, due to the large variation in rations fed on different farms. On any given farm, larger smolts were usually fed a higher ration. Above 100 g, the unit ration through October 1995 was somewhat higher, ranging from about 1080 g for 100- to 120-g smolts to 1400 g for large S_2's. These latter values are based on very few cages. Based on the data presented above, it would appear that many farms are probably under-feeding their smolts in the first summer. This may or may not mean that insufficient feed is provided, as the amount of wasted feed is unknown. The scatter in the points of Fig. 56 suggests that this might be quite variable from cage to cage.

To see if feeding rates had any significant relationship with FCR or SG for the first summer, multiple regressions of these two parameters on feeding rate and ration residual were performed. The only significant relationship was the influence of ration residual on growth rate, as previously indicated in Fig. 56. There was a suggestion that feeding rate may have some influence on FCR ($p=0.10$), with faster feeding rates being associated with higher FCRs. This will be addressed again for the second summer data.

Beginning of the second summer

The ration-growth relationships were next examined through the end of June of the second summer (up to the start of the final phase of rapid second summer growth). Due to the compressed time period for these measurements, date of measurement had no effect on calculated FCR over this time period. As with the data up to the end of October 1995, specific growth rate through June 1996 was significantly correlated with unit ration - the more feed per fish added to the cage, the faster they grew (Fig. 57). Again, the unit ration residuals of Fig. 57 were based on the average rations fed different size classes of smolts up to June 30, 1996. As with the data for the first summer, the influence of smolt size on ration is not obvious due to the great variation in rations fed (Table 21). Again, ration was second only to smolt size as an influence on specific growth rate. A 200-g per fish increase in ration from smolt entry to June 30, 1996 would, on average, result in an increase in growth rate of 0.012% per day.

Unit feed conversion ratios were negatively correlated with specific growth rate through June 30 1996 (Fig. 58). Thus, the cages exhibiting the highest growth rates had the most efficient feed conversion. This differs from the first summer's data (Fig. 55) in that the relationship is much better defined between FCR and growth rate, possibly because of the fact that unit FCR changed with time in the first summer and masked the relationship. Time was not a significant factor for either growth or feed conversion for the second summer's data.

As with the first summer, growth and feed conversion appeared to be better in the cages that received the highest unit ration. Again, a lot depends on the amount of wasted feed in interpretation of these data. Variation in this factor may account for much of the scatter of the points of Fig. 58.

Unit feed conversion ratios for feeding through June 30, 1996 were highly correlated with unit FCR's for the first summer (Fig. 59). Cages that were fed more efficiently in the first summer usually continued to be fed more efficiently into the second summer.

As with the first summer's data, the influence of feeding rate on specific growth rate and FCR through June 1996 was examined by regressing these parameters on feeding rate and ration residual. As indicated in Fig. 57, growth rate residual was significantly correlated with ration residual.

A linear regression analysis of growth residual against feeding yields a weak relationship ($p=0.08$). A multiple linear regression of growth rate against feeding rate and ration residual yielded a significant relationship that suggested that farms fed fastest tended to have lower growth rate residuals ($G = 0.0225 - 0.0242$*feed rate $+ 0.0001$* ration res.; multiple $R^2 = 0.4$, $p = 0.002$).

Feeding rate was significantly correlated with FCR residuals through June 1996 ($p = 0.028$), indicating that faster feeding rates led up to higher FCRs, confirming the suggestion of such a

relationship for the first summer (FCR res = -0.1781 + 0.2054*feeding rate - 0.0002* ration residual; multiple $R^2 = 0.24$, $p = 0.04$).

Rations up to harvest

Analysis of feed conversion efficiency from smolt entry to harvest is difficult due to the variable harvest strategies used for the various cages (i.e. variation in months harvested and amounts fed prior to harvest). Logically, the most significant factor influencing average harvest weight (ungutted) was the total unit ration (the unit ration from smolt entry to harvest (Fig. 60)). The more fish were fed, the larger they were at harvest, irrespective of initial smolt size. However, the time from smolt entry to harvest tended to be longer for smaller smolts (Table 21, last column).

The relationship between unit FCR and unit ration from smolt entry to harvest differed from that obtained through June 1996, where FCR was best for fish in cages that were fed the most and which had the fastest growth. For the period from smolt entry to harvest, FCR increased with increasing ration (Fig. 61). This suggests that, contrary to the time up to June 30 1996, fish were not underfed for the last summer. Since 2/3 of the total unit ration is fed in the second summer, this period is the most influential in determining the overall FCR. There may be a psychological factor at play, where during the few months prior to harvest, the fish are fed more intensely.

From Fig. 61, we see that 1/3 of the variance in unit feed conversion ratio is accounted for by the total unit ration - generally the higher the total unit ration, the higher the total unit FCR. Can any other factors be identified which contribute to the scatter of points in Fig. 61? The general relationship may be related to environmental factors. The larger total unit rations were fed generally to fish that were harvested later in the year (February-April 1997). Perhaps FCRs are lower at lower temperatures. Also, getting into the second winter, there may be more maturing fish which are losing weight and would thus contribute to a higher FCR. At any rate, the line in Fig. 61 represents an average for industry performance in terms of feeding efficiency. Again, total unit FCR residuals may be calculated as the vertical distance between the position of each point (each point representing a cage) and the regression line. Points above the line have positive residuals, indicating relatively poor feed conversion.

In Table 22 the cages are ranked in order from higher to lower feed conversion efficiency, based on residual values (column 6). Average harvest weight accounts for about 40% of the variance in these residuals (Fig. 62). Cages with negative residuals were more efficient than expected, based on the rations applied to them. Cages with smaller harvest weights usually performed more poorly than expected. In a way, this result is consistent with the results up to June 1996 where lower FCRs were correlated with higher specific growth rates.

Initial smolt size had no significant effect on either average harvest weight or average total unit FCR (Table 21), but did influence the average harvest times (last column, Table 21). The average time from smolt entry to harvest was 23.5 mo for 40- to 60-g smolts, decreasing to about 20 mo for 120- to 140-g smolts. The harvest patterns for various sized smolts are shown in Fig. 63. The lines represent a 3-mo running average. The monthly total fish harvest from the monitored cages is shown in Fig. 64. The main harvest period was October 1996-May 1997, with dips in numbers harvested coinciding with Christmas and Easter.

Growers may find Table 20 a useful table, where the average monthly unit rations are given for various sized smolts, 95% confidence limits in parentheses. Again, these are converted to moisture-free values. To convert back to moist feed, divide the number by 0 .78; to convert back to dry feed, divide the number by 0.93. By way of illustration, the average monthly unit ration for 40- to 60-g smolts in July 1995 was 104.1 g per fish. The confidence limits are ±-20.1 g, so that 95 times out of 100, the rations should fall between 104.1-20.1 = 84 g and 104.1+20.1 = 124.2 g. Where values in parentheses are lacking, the number of cages is insufficient to provide an estimate of the confidence limits.

FISH SIZE DISTRIBUTIONS IN CAGES OF FARMED SALMON

In addition to estimation of the average weight of salmon in cages, the farmer may find it useful to know something of the size distribution of fish in the cages. For instance, estimation of how many market fish of each size class are present may

influence marketing strategies. Estimating size distributions entails somewhat more effort than estimating average weights.

Many animal populations show a size distribution similar to what is generally known as a "bell-shaped" or "normal" distribution, as shown in Fig. 65. This curve is characterized by two components: the average size (u) and the standard deviation (s). For example, if you have a cage of 10,000 fish whose size distribution fits the pattern of Fig. 65, with an average weight of 8 lb (u = 8) and a standard deviation of 1 lb, then 68% of the fish (6800) will fall within the range of 7-9 lb, and 95% will be within the range of 6-10 lb. As will be shown later, the size distribution of salmon in cages is usually more variable than this example.

Figure 66 shows how a difference in the standard deviation affects the distribution of fish sizes, although the average size is the same for both curves. For the population with a standard deviation of 0.5, the fish are more tightly grouped near the average weight.

The calculation of the standard deviation, s, is shown in the following example. If 10 fish are weighed, and these weights are obtained: 4.8, 3.7, 5.8, 4.7, 4.1, 3.8, 5.3, 5.5, 6.6, and 8.2 lb, then the sum of these weights is 52.5 lb, and the average weight (u) is 52.5/10 or 5.25 lb. To get a standard deviation, the differences between the average weight and the weights of each fish measured must be determined. These differences are: 0.45 (5.25-4.8), 1.55, -0.55, 0.55, 1.15, 1.45, -0.05,-0.25, -1.35, and -2.95. The sum of these differences is zero, because there must be as much weight above the average as there is below. To get around this, each difference is squared, so that everything becomes positive:

0.45*0.45 = 0.2025
1.55*1.55 = 2.402
-0.55*-0.55 = 0.3025
0.55*0.55 = 0.3025
1.15*1.15 = 1.3225
1.45*1.45 = 2.1025
-0.05*-0.05 = 0.0025
-0.25*-0.25 = 0.0625
-1.35*-1.35 = 1.8225
-2.95*-2.95 = 8.7025

The sum of all these squared differences is 17.225. The standard deviation is obtained by taking the square root of the sum of the squared differences divided by the number of fish measured minus one; = 17.225/9 = 1.939 = 1.38 lb. So that the measurements suggest that about 2/3 of the fish in this cage are between 5.25 - 1.38 = 3.87 lb and 5.25 + 1.38 = 6.53 lb.

This process is tedious if you have measured many fish, and there are shortcut methods (e.g many statistical software packages) which do all these calculations for you. The other descriptive statistic that I will use in this section is the "coefficient of variation" (cv), which is the standard deviation(s), divided by the average weight and multiplied by 100 to express it as a percentage. In the above example, the coefficient of variation is (1.38/5.25)*100 = 26.3%. Thus 2/3 of the fish in this cage should weigh plus or minus 26.3% of the average, and 95% should weigh plus or minus 52.6%. As will be seen, a coefficient of variation of 26.3% is well within the normal values obtained for cages of fish.

In Fig. 67 the coefficients of variation for all the weight measurements of fish taken during this survey of 20 farms are shown. The cv's for samples of smolts taken at the beginning of the project are circles, those for measurements of fish in cages during the first summer's growth are x's, and those for measurements of fish in cages during the second summer's growth are dots.

The average coefficient of variation for smolt samples collected in the spring of 1995 was 14.8%, and showed no trends with smolt size. So, for a typical smolt sample with an average weight of 50 g, 2/3 of the fish would lie between (50+50*0.148) and (50-50*0.148) = between 57.4 and 42.6 g. For a sample with an average weight of 100 g, 2/3 should fall between 85.2 and 114.8 g, 95% between 70.4 and 129.6 g. The fairly small coefficient of variation, of course, reflects the sorting into size grades by hatcheries.

The coefficient of variation, and hence the variation in cage fish size, increases throughout the first summer in the cage (Fig. 67). The average for all samples in the first summer in the cage is 24.3% - an increase of about 10% over that for smolt samples. However, it is probable that the cv increases throughout the first summer, reaching an average value close to that obtained from cage fish data in the second summer toward the end of the first summer.

The increase in the coefficient of variation during the first summer's growth no doubt reflects high variability in feeding of individual fish and resulting growth during the first few months in the cage.

The coefficients of variation for the second summer's growth (dots in Fig. 67) show no trends with increasing fish size. The average for the second summer is 30%. Thus, for the average cage of fish, two-thirds of the fish are within 30% of the average weight throughout the second summer's growth. For example, if the average weight is 2000 g, then 2/3 of the fish will be between 1400 and 2600 g (30% of 2000 = 600), and 95% will be between 800 and 3200 g.

All of the discussion to this point assumes that the distributions of smolt and cage sizes are similar to the "normal" distribution, as described in Fig. 65. This assumption needs to be confirmed. One of the common ways in which a distribution can differ from a normal one is by being skewed one way or the other. For example, the curve in Fig. 68 has a "tail" of fish to the right which are heavier than most of the fish in the distribution. Thus, the curve is said to be skewed to the right, or positively skewed. If, instead, the distribution has a long tail to the left, composed of small fish, the distribution is said to be negatively skewed. There are statistical methods for skewness, but they are a bit complicated. Suffice it to say that for 46 samples of smolts, only 3 were significantly skewed - all positively. Figure 69 is a composite distribution of all 46 smolt samples with a total of 608 smolt weights. For this composite distribution, 69.3% of all smolts sampled were within plus or minus 1 standard deviation of the average (u), and 97.7% were within plus or minus 2 standard deviations. This is pretty good agreement with the 2/3(66.7%) and 95% values predicted for the normal distribution, with the fish clustered a bit more closely around the average. One quirky characteristic of the curve in Fig .69 is the "notched peak", with the number of fish occupying the mean value being less than the two areas of the curve on either side of it. This may be due to the relatively small sample size used to generate the distribution.

The distributional characteristics of fish measured during the first summer's growth were not investigated because the distribution is probably changing, and is probably between that for smolts and the distribution characteristic for second summer fish which will be discussed next.

The size distributions of fish in their second summer of cage growth were somewhat more complicated than the smolt size distributions. Fifty-seven of the 64 samples (100 fish per sample) exhibited positive skewness, with 26 of these being statistically significant. So there is a decided tendency toward positive skewness in second summer fish. In other words, for a typical distribution, there is a small percentage of very large fish forming a "tail" to the right of the distributional curve - as in Fig. 68. These fish may be the dominant fish in the cage.

Figure 70 is a composite distribution of the weights of 1800 fish, combining samples from 18 cages. For this distribution, 69.5% are within plus or minus 1 standard deviation, and 96.9% within 2 standard deviations. These values are again somewhat higher than the 67% and 95% characteristic of the normal distribution, and may be a carry over from the hatchery grading process - so that the size distributions are a bit more uniform than normal. The "skewed" tail to the right is also apparent. If the distribution were perfectly symmetrical, then of the 3.1% of the fish (55 fish) lying outside ±2 standard deviations, 1.5% would be on each end of the distribution. Actually 45 of the 55 fish are greater than 2 standard deviations, and only 10 less.

Also, because of the skewed distribution, there are more fish below average weight than above. These are balanced off by the few very large fish forming the tail to the right. However, this bias is small enough that it may be disregarded for practical purposes.

To review the calculations, suppose that the farmer has a cage of 10,000 fish with an average weight of 8 lb and a coefficient of variation of 30%. If these fish have a typical weight distribution, as in Fig. 70, 69.5% of the fish (6950) will weigh between 8 - (8*.3) and 8 + (8*.3) or 5.6 and 10.4 lb, and 96.9% will be between 8 - (8*2*.3) and 8 + (8*2*.3), or between 3.2 and 12.8 lb. Since 6950 fish were within ± 1 standard deviation, then 9690 - 6950 = 2740 fish will be either 3.2-5.6 lb or 10.4-12.8 lb, probably close to half in each category. Of the remaining 3.1% of the fish (310), 80% (240-250) should weigh more than 12.8 lb (the fish in the "tail"). Almost all of these will be between 12.8 and 15.2 lb (between +2 and +3 standard deviations). The other 20% (60-70 fish) will weigh less than 3.2 lb.

To summarize:

less than 3.2 lb	:	65fish
3.2-5.6 lb	:	1370
5.6 to 8 lb	:	3475
8 to 10.4 lb	:	3475
10.4 to 12.8 lb	:	1370
more than 12.8:		245
Total	:	10,000 fish

The above calculations can be similarly calculated for any number of fish if the total number of fish, the coefficient of variation, and the average weight are known.

GROUPING FARMS BY HUSBANDRY VARIABLES

In a previous section, the farms in the survey were clustered by environmental variables. We now present the results of a cluster and discriminant function analysis, based upon husbandry variables. As with the environmental analysis, the clustering method was agglomerative centroid clustering (SPSS). Unlike the environmental analysis where all the cages on a farm were assumed to be subject to the same environment, each cage had to be clustered as various cages on a farm might be subjected to differing husbandry practices (smolt size, feed type, etc.). The husbandry variables used (Table 23) were cage size (small (1), medium (2), large (3) or extra large (4)), smolt size, feed type (moist or dry, expressed as a percentage of the total ration that was moist feed), observed feeding rate for the first summer, observed feeding rate for the second summer, cage shape (circular (1) or square (2)), and total unit ration. For some farms where feed data were not provided, it was estimated, assuming the industry average for FCR. All variables were normalized by dividing individual values by the respective means.

Eight clusters and seven outliers were identified among the 47 cages for which all husbandry variables used were available as tabulated (Table 23).

Scanning the cluster composition, cluster 1 is composed entirely of 70-m circles containing small to medium sized smolts that were fed almost entirely on dry feed. Cluster 2 differed from cluster1 only in that the smolt sizes were all greater than 100g. Cluster 3 was composed of square steel cages, and the fish were fed mostly on moist feed. The feeding rate for the first summer was much higher for this cluster as well. Cluster 4 consisted of small to medium round cages that were fed almost entirely on moist feed. Cages of cluster 5 differed from those of cluster 1 only in feeding rates, which were much higher, particularly in the second summer. Cluster 6 consisted of three, 70-m circles that were fed mostly moist feed. Cluster 7 was composed of three small wooden cages that received almost all-dry feed, and cluster 8 was characterized by very high feeding rates in the second summer. The outliers either had unusually high feeding rates, or had unusual combinations of diet and cage size or shape.

A discriminant function analysis was performed on the clusters to determine which husbandry variables were significantly correlated with the various clusters. The first four discriminant functions accounted for nearly 99% of the variance associated with the clusters (Table 24).

The correlations between the discriminating variables and the canonical discriminant functions are shown in Table 25.

Thus, function 1 was most highly correlated with feed type and cage type, function 2 with cage size and feed type, function 3 with cage type, and function 4 with feeding rate in the second summer.

The cages are located in space defined by the first two discriminant functions in Fig. 71. As indicated in Table 25, function 1 is most highly correlated with cage shape and feed type, with square cages and moist feed having higher scores along the function 1 axis. Function 2 is most highly correlated with cage size, larger cages having higher scores along that axis. Clusters 2 and 5 are not well separated from cluster 1 on the first 2 discriminant functions. Cluster 2, with larger smolts, separates from 1 mainly on the function 3 axis, and cluster 5 along the function 4 axis.

Cage size and shape are significant variables influencing fish growth and feeding efficiency (c.f. figures in section on rations). An analysis of variance on feeding efficiency of various sized cages (using unit FCR residuals of Table 22) indicated that 70-m circles had a significantly better average feed conversion (average FCR was 0.093 below the industry average, with 13 of 15 cages having better than average feed conversion). In contrast, smaller circular cages had average FCRs 0.078 units above the industry average, and square

cages had FCRs 0.075 units above the industry average (Table 26). Since there was a tendency for most 70-m circle cages to receive dry feed, and a tendency for most square cages to receive moist feed, the higher FCR for 70-m circles may be influenced by feed type. Automatic feeders were also used only in 70-m circles. Separating these interactions is not possible in this study.

FIN CONDITION: HARVESTED FISH

Fin condition of harvested fish is of minor importance to the fish farmer, in so far as affecting appearance and possibly attractiveness for sale.

As described in the Methods, a value from 0-3 (to the nearest 0.5) was assigned to each of the dorsal, caudal, paired (combined) fins and operculum, with 0 indicating a perfect fin and 3 indicating total fin erosion. The values for each were then summed to provide an index of fin erosion. As the dorsal and caudal fins usually suffered the most severe erosion, they weighed most heavily in the total score.

Fin condition improved as the harvesting proceeded, with fish harvested in August and September having the poorest fin conditions (Fig. 72), with indices of 3 to 4. By March-May, indices for salmon from 70-m plastic circles were under 2, and were about 2.4 for salmon from square steel cages. The fin indices for salmon from the large circular cages were significantly better than those from square steel cages (Table 27), and probably for fish from smaller circular cages as well, although fewer samples were available for analysis for these. The trend is also apparent for individual farms where sufficient samples were taken (Fig. 73). Mature salmon showed a similar trend (Fig. 74) with fin condition improving as the harvest season progressed. Differences between male and female salmon were not consistent for either mature or immature salmon. The mean fin condition for immature males was 2.12, that for females was 2.19.

Mature fish tended to have better fin conditions than immature fish (Table 28).

Reasons for the trend toward better fin condition as the harvest progresses are conjectural. Perhaps the most reasonable is that cooler temperatures reduce the activity of microorganisms responsible for fin erosion. It may also be true that fin condition is correlated in some way with stress, which may be reduced at lower temperatures or lower densities of fish as harvest proceeds. Less stress may also be an explanation for better fin condition of salmon from the larger cages.

LIPID CONTENT: HARVESTED FISH

The lipid content of harvested salmon averaged about 9% (Fig. 75), with no difference between males and females. Mature salmon had very low lipid content, less than 2%. The very high values, in excess of 20%, may be in error – perhaps as a result of the conditions in the processing plant where the fat meter was used.

DISCUSSION

SMOLTS

The poorer general fin condition of the smaller smolts may relate to stress-related factors in the hatcheries. Small fish may be subjected to the aggressive behavior of larger fish in the tank. The validity of this speculation is subject to the amount of grading carried out in the hatchery prior to sale. Water chemistry may also be a factor. There is some evidence that soft water may result in more fin erosion than hard water. The relatively better fin condition for smolts from recirculation hatcheries may be due to the calcium added to buffer the recycled water.

Most lots of smolts tested in the salinity tolerance tests showed excellent survival. Smaller smolts exhibited higher mortalities, both in the salinity challenge tests, and in the first few weeks after cage entry. It would thus appear that transfer to seawater is somewhat more stressful to smolts under 60 g. Two samples of smolts which experienced heavy scale loss during shipment also exhibited poor survival in the salinity challenge tests. Smolt shipping containers with high concentrations of loose scales in the water upon arrival at the sea cages are possibly indicative of higher than normal subsequent post-smolt mortality.

The reliability of the salinity challenge test in assessing smolt quality has been demonstrated several times in laboratory studies (e.g. Komourdjian et al. 1976; Saunders and Henderson 1970, 1978; Saunders et al. 1985).

Samples of small smolts tended to have higher proportions of males than did samples of larger smolts. This may be due in part to the

tendency for male parr to become precociously mature and cease growth toward the end of the first summer. This phenomenon may also explain the high proportions of male S2 smolts. Some of these trends may be offset by the practice of some hatcheries in culling mature males prior to sale.

Transfer of smolts to sea cages is a stressful experience for smolts, with several coincident physiological changes: 1) Smolts transferred to seawater begin to ingest seawater to compensate for osmotic loss. This ingestion may amount to 7 mL kg^{-1} h^{-1} after 3–4 d in seawater (Usher et al. 1990). This ingested water may affect digestion temporarily by alteration of the water content of digested food and hence affect mechanical processing, by altering pH of gut contents, or by having water transport across the gut interfere with nutrient uptake. 2) Growth hormone levels rise following transfer to seawater by as much as 250%; this rise is possibly important for osmoregulatory function in seawater (Sweeting and McKeown 1987; Bjornsson et al. 1998). 3) Blood glucose declines, possibly associated with the metabolic demands of hypoosmoregulation (Sweeting and McKeown 1987). 4) Smolting and seawater entry is associated with a rise in blood cortisol levels, which may lead to a transient decrease in immunological defenses to pathogens. Perhaps related to increased cortisol levels is a transient decrease in blood immunoglobulin and serum protein, resulting in a reduced ability to generate antibodies (Eggset et al. 1997).

SWIMMING SPEEDS IN SEA CAGES

Swimming speed of salmon affects appetite and growth (e.g. Totland et al. 1987; Jorgensen and Jobling 1993). Groups of salmon that are constantly swimming have reduced aggressive behavior, less variable growth rates, higher feed intake, and more efficient food conversion at moderate swimming velocities. Constantly swimming salmon may also have higher concentrations of epidermal cells, which may be important in protection against microorganisms.

The fish observed in this study had an average swimming speed of 43.9 $cm \cdot s^{-1}$, which did not appear to depend upon fish size or temperature – within the temperature range over which velocities were measured (5–13°C).

The measured swimming speeds have to be qualified in that any water currents in the cages were not taken into account. Petrell et al. (1997) found that swimming speeds of salmon at the surface were less than those at depth. Since all our measurements were for fish near the surface, the mean velocities for all fish may have been higher. Petrell et al. (1997) obtained swimming speeds of 10–65 $cm \cdot s^{-1}$, with a mean around 30 $cm \cdot s^{-1}$ for fish ranging in size from 2-9 kg. No influence of size on velocity was indicated. The swimming speeds of chinook salmon (100– to 1600-g size range) in the same study averaged 35–40 $cm \cdot s^{-1}$. Swimming speed may be influenced by such variables as ambient water current velocity and cage shape. Some of the differences between our values and those of Petrell et al. (1997) may be due to differences in these variables. Boucher and Petrell (1999) found typical swimming speeds of 2– to 3-kg Atlantic salmon of 0.85 $bl \cdot s^{-1}$ (range of 0.57–1.32). This is very similar to the velocities determined in this study for fish of similar size (Fig. 17). Kadri et al. (1991) observed swimming speeds of Atlantic salmon in net pens to vary rhythmically, being higher in early morning and evening (ca. 1.2 $bl \cdot s^{-1}$), and with a minimum near mid–day (ca. 0.4 $bl \cdot s^{-1}$) for 1-kg fish. Our observations were made near mid–day ± 2 h, and were post-feeding, so they may be minimal values.

FEEDING PATTERNS

Two significant trends observed with respect to the feeding of salmon in this study were: 1) the rate of feeding (grams of feed per kilogram of fish per 100 s) declined as the fish grew; and 2) fish in small cages tended to be fed more rapidly than fish in large cages. These two trends are related in that small cages naturally have lower biomass for a given fish size.

Experimental feeding trials have indicated that if the food is presented in a fashion that is predictable in time or space, then the distribution of food among the fish in a group becomes more uneven (Thorpe et al. 1990; Grant and Kramer 1992; Jobling and Baardvik 1994; Kadri et al. 1996). If food is presented in a predictable fashion (e.g. a point source from an automatic feeder), then the dominant fish in a cage will occupy positions near the food source and acquire most of the feed (e.g. McCarthy et al. 1992; Thomassen and Lekang 1993). Under such conditions, the coefficient of variation in fish size tends to increase with some subordinate fish obtaining little or no food. From this point of view, it is desirable to spread the food

applied to the cage over as wide an area as possible (Abbott and Dill 1989). It has also been found that high stocking densities and water currents are effective in reducing competition for feed, resulting in less variability in growth rate among fish in a cage (Jobling and Baardvik 1994). It should be noted that competition for feed among salmon in sea cages is not so intense as among juvenile salmon in fresh water (Kadri et al. 1996). There is little indication of outright aggressive behavior in sea cages, but subordinate fish will veer off if attacking the same food pellet as a more dominant fish in the cage. This sort of interaction is probably the sort of behavior leading to increased variability in growth rate. It has also been postulated that subordinate fish convert feed less efficiently than dominant fish due to stress–related physiological changes (Abbott and Dill 1989). Thus, any feeding practice that reduces competitiveness should result in less variable (as well as higher) growth rates in a cage.

Feeding rate can thus be critical in affecting both magnitude and uniformity of growth within a cage. If the fish are fed too slowly, then the dominant fish will get a disproportionate amount of the feed – particularly if the ration is less than sufficient for satiation (Davis and Bolla 1987; Grant and Kramer 1992). On the other hand, if fed too rapidly, then the appearance of satiation may occur before many of the fish in the cage are in fact satiated (e.g. Ang and Petrell 1997) – particularly if surface feeding ("boiling" or "feeding frenzy") is used as an indication of satiation. From a consideration of the relation between feeding time and boiling time (Fig. 19) and the relationship between feeding rate and cage biomass (Fig. 25), we conclude, in many cages, that cages with low biomass were being fed at feeding rates that were too high. This is probably more of a problem for small cages where biomasses tend to be lower. Because, as has been shown in the results sections dealing with growth, rations, and feed conversions, many cages are being underfed, it is probable that many cages with low fish biomass were fed too rapidly and too little ration. Underwater cameras to assess satiation were not used on any of the farms during this study, but are in increasingly common usage on salmon farms at present. It has been shown that the proper use of these cameras to monitor feed usage can result in better control of feeding rates and assessment of satiation (Ang and Petrell 1997). It has also been suggested (Brown et al. 2000) that periods of "feeding frenzy" or "boiling" are stressful in that higher bacterial levels in the cage water are increased by dislodgment from the netting. They suggest low-level, continuous feeding to reduce feeding frenzy during the main feeding periods.

The data generated in this study cannot be used to develop optimal feeding rates. Some of the feed suppliers have developed models for this; much of the information is of a proprietary nature. Suffice it to say, that a general impression was gained that a feeding rate of slightly less than 1 g per kg fish biomass per second (i.e. slightly below where the curve of Fig. 25 flattens out) would be near optimum for the conditions under which feeding was observed. It is probable that the higher feeding rates observed for biomasses of 8000 kg and less are excessive. It must also be pointed out that optimal feeding rate may vary with temperature. Growers should make frequent estimates of the biomass in their cages, in order to estimate proper rates of feeding.

Kadri et al. (1991) found that the appetite of salmon in net pens varied rhythmically in synchrony with the activity rhythm. Feeding fish at night, however, is not practical. And the feeding rhythm may shift seasonally, as salmon tend to be active diurnally in summer, shifting to crepuscular in late autumn and winter.

GROWTH RATES

There is little in the way of published values for specific growth rates of pen–reared salmon that can be compared to the growth rates determined in this study. Austreng et al. (1987) published specific growth rates for salmon of various sizes for temperatures ranging from 2-14°C in a Norwegian fjord. These growth rates and those generated in this study (model 3) are compared in Table 29 for comparable temperatures and fish weights.

The growth rates are similar, in spite of the differing temperature histories in the two studies.

Allen et al. (1972) published a calculated growth curve for wild Atlantic salmon in the northeast Atlantic. We will compare the sizes estimated from this curve with sizes attained by cage–reared salmon in this study after similar lengths of time in seawater. Since the curve generated by Allen et al. is for length, we have converted to weight assuming a condition factor of 1.05 (see section on calculation of condition factors). Weights of 160, 260, 400, 2890 and 5600 g were estimated for July 31, August 31, and September 30

of year 1, June 30 of year 2, and March 31 of year 3, respectively. Typical weights of cage–reared fish for these periods of time are: 130, 240, 500, 1250, and 5000 g. Smolt size was listed as 15 cm for the wild data – ca. 30 g, and we have used data for 40-g smolts for comparison. The greatest discrepancy between the two sets of values is for the end of June of year 2, where the estimated size of wild fish is over twice that for cage–reared fish. The difference may be due to the differing over–winter temperature regimes to which the two groups of fish are subjected. Bay of Fundy winter temperatures may be lower than those in which wild salmon spend their first seawinter. Some of the difference may also be due to some smoothing of the growth curve for the wild fish.

SEXUAL MATURATION

Maturing salmon are characterized by loss of weight and condition, appearance of external secondary sexual characteristics (hooked lower jaw in males, darker color), decrease in muscle fat and protein content, increase in muscle water content, loss of flesh color, and decrease in weight of viscera (Aksnes et al. 1986).

The decision to mature is apparently made more than a year prior to spawning. Salmon that will mature as grilse become noticeably heavier and in better condition than non–maturing salmon in the first fall in sea cages (e.g. Kadri et al. 1996). Maturing fish may be of no greater length at this time. The difference in condition peaks in April, coincident with increased appetite and faster growth rate at this time for fish that are committed to maturation. By June–July, this increased appetite disappears, and the maturing salmon become increasingly anorexic. Weight and condition factor then begin to decline in maturing fish, and from September onward maturing fish will tend to have lower condition factors than immatures (Aksnes et al. 1986). The results obtained in this survey agree with these findings generally (Fig. 49, 50) (which are primarily from research done in Scotland and Norway), as mature fish had increasingly lower condition factors than immature fish from early October onward. Duston and Saunders (1999) also found the best predictor of maturation to be an increase in condition factor in May–June of the second summer.

The increased appetite and feed intake in April results in a higher fat content in maturing salmon at this time, and it has been suggested that a fat content of at least 12% is required for subsequent spawning in the fall (Thorpe et al. 1990).

Depriving salmon of food for a period of time during the winter to spring prior to spawning as grilse has been found to reduce the percentage of fish that will mature (Thorpe et al. 1990; Reimers et al. 1993; Duston and Saunders 1999). February to March has been generally found to be the most effective months to apply food deprivation. The mechanism is presumably elimination of the peaks in condition factor and fat content, which seems a requirement for maturation.

Use of continuous light in the winter prior to spawning may also result in a lower incidence of maturation (Berg et al. 1996; Oppedal et al. 1997, 1999); however, in some cases the effect has been only a 8-25% reduction (e.g. Berg et al. 1996). Reduction of the number of maturing fish may be more critical in Norway and Scotland where percentage maturation may be 10–50%. The overall percentage of mature fish in this study was about 4% (8% for males). The colder winter temperatures experienced by caged salmon in the Bay of Fundy may be effective in reducing the percentage of fish maturing. Less reduction in day length in winter may also have an effect.

DRESSOUT WEIGHT LOSS

The mean weight loss from gutting (12.6%) is very near to the mean obtained by Johansen and Jobling (1998) for a Norwegian strain of salmon. For this study the dressout losses ranged from 9.5-15% of the total fish weight. Their values show less scatter than ours because the sampling errors in our data were not present in theirs.

FACTORS AFFECTING GROWTH AND CONVERSION EFFICIENCY

Ration

If we exclude environmental factors, such as temperature, over which the cage farmer has little control (once a site is selected), ration is obviously the most influential factor affecting salmon growth and conversion efficiency. Figure 76 illustrates the classical relationship between ration, growth and conversion efficiency (adapted from Fowler and Burrows 1971). If the ration is above the maintenance level – required to just sustain bodily

functions of the fish – then the fish will grow, the rate of growth being proportional to the ration up to the point where ration approaches the maximum feeding level – controlled by appetite and the capacity of the digestive system. Feed conversion will improve with increasing ration up to the "optimum" ration where feed conversion is most efficient. Above this optimum ration, growth rate continues to increase, but the FCR also rises. It is important to note that the relation between FCR and ration changes from one side of the "optimum" ration to the other. At rations below optimum (inset A), the FCR improves (=decreases) with increasing ration. This is the relationship we observed for the cages in the survey for the first summer, and up to June of the second year, from which we suggested that most farms were feeding below optimum rations over this period.

At rations above optimum (inset B), FCR rises as the ration is increased. This relationship was observed when FCR from smolt entry to harvest was plotted against total ration from smolt entry to harvest. However, as was pointed out in the results, and as will be discussed below, the situation is somewhat more complex due to varying fish size at harvest and varying harvest times. As pointed out in the results section, the amount of feed delivered to the cages, but uneaten, is an unknown variable that may have considerable impact on the observed relationships.

Ration not only influences growth rate, but also influences the variability in fish size in a cage. The term "growth depensation" refers to the increase in variance of the size-frequency distribution with time, due to differences in individual growth rates in a cage (e.g. Abbott and Dill 1989). Groups of fish fed higher rations have been found to have a lower degree of growth depensation (less variation in size at the end of the feeding trial) (Kadri et al. 1996). This is presumably due, in part, to less competition for food at higher rations. Davis and Olla (1987) observed more aggression and greater growth depensation in groups of chum salmon fed at lower rations. We did not investigate a possible relationship between ration and variance in fish size with this study because our weight measurements were performed over a period of time, and the variance in fish size increased primarily in the first summer.

Exercise

Moderate exercise (swimming speeds up to 1–1.5 $bl \cdot s^{-1}$) results in better appetite, increased growth (e.g. Totland et al. 1987; Jorgensen and Jobling 1993), decreased growth depensation, and higher condition factor. Fish that are exercised also have higher quality flesh (lower muscle glycogen and triglycerides). The observed apparent swimming speeds for the smolts in this study were above moderate and those for larger fish were below moderate.

Fish size

In general, larger fish convert feed to flesh less efficiently than smaller fish (particularly when the ration level is high) (Paloheimo and Dickie 1965; Wurtsbaugh and Davis 1977; Johansen and Jobling 1998). This is attributed to the fact that (presumably at high ration) food intake relative to body mass decreases more rapidly than does energy expenditure. This relationship is probably one of the factors influencing the trend of higher FCRs with increasing total unit ration obtained in this study.

Stocking density

Higher stocking densities have been found to reduce growth depensation and aggressive behavior (Refstie and Helson 1976).

Feeding rhythms

The appetite of Atlantic salmon may vary rhythmically over a 24-h period, and the timing of this rhythm may change seasonally (Kadri et al. 1991). Salmon tend to feed more diurnally at higher water temperatures, with appetite peaking at dawn and dusk. Swimming velocity is related to appetite; the hungrier the salmon are, the faster they swim. Low temperatures (less than 6°C) tend to induce salmon to become more nocturnal in their feeding habits (Fraser et al. 1993, 1995). It should be remembered that these results were obtained from studies in Scotland, and photoperiod–temperature interactions could alter the relationship for salmon in the Bay of Fundy.

Previous feeding history

Fish that have been previously starved tend to eat more (Talbot et al. 1984; Nicieza and Metcalfe 1997). Not adjusting for this compensatory increase in appetite can result in providing lower ration, and possibly higher FCR, if one is feeding according to a schedule. This may be an important factor when weather prevents feeding caged fish for several days.

FACTORS AFFECTING FIN CONDITION

There has not been a lot published on factors influencing fin condition of cultured salmon. Both Jorgensen and Jobling (1993) and Abbott and Dill (1989) consider the degree of fin erosion to be stress related. In their studies, dominant fish had less fin erosion than did subordinate fish. Jorgensen and Jobling (1993) suggested that the better fin condition from groups of exercised fish was related to less agonistic activity in these groups. If fin condition is related to stress, whether from aggressive behavior or other factors, then our results suggest that fish in the larger plastic circles were generally less stressed than those in square steel cages. Our findings also suggest that, whatever the stresses are that are responsible for fin erosion, they are less influential under winter conditions, as the fin conditions tended to improve through the winter months.

LIPID CONTENT OF HARVESTED SALMON

The mean muscle lipid levels of harvested salmon that we obtained (9%) are similar to those published in other studies. Koskela et al. (1997) reported mean muscle lipid levels of 8.1-9.3%, depending upon the rearing temperature – less lipid being deposited at lower temperature (temperatures tested ranged from 2-6°C). These results were for fish of about 150 g, and the experiments were performed in fresh water. Johansen and Jobling (1998) found that the percent lipid increased with increasing fish size at slaughter (ca. 2.2 kg). Percent lipid was found to increase as 2.343 + 0.0025*fish weight (g). This would translate to 14–15% for 5-kg fish. This, however, represents a considerable extrapolation from the size of fish used in their study.

The lower lipid content of mature fish has been reported previously (Aksnes et al. 1986), who found the fat content of salmon fillets to decrease from 12 to 5% as maturation advanced.

CONCLUSIONS

- Almost all smolts stocked in study cages showed excellent salinity tolerance. Two factors were found to result in poorer salinity tolerance. Small smolts (less than 60 g) had higher mortalities upon transfer to seawater. Batches of smolts exhibiting excessive scale loss in transit exhibited higher mortality when tested for salinity tolerance.

- Measured swimming speeds tended to be constant at an average of near 40 $cm \cdot s^{-1}$, irrespective of fish size or temperature (over a temperature range of 4-13°C). These measurements were made on fish swimming near the surface, immediately after feeding. Salmon in square steel cages swam more slowly, on average, than did those in 70-m plastic circles.

- The rate at which feed was delivered to a cage was determined largely by the biomass of fish in the cage, feeding rate being inversely proportional to biomass. It is possible that cages of small fish (first summer, low biomass) are fed at too high rates for many of the study cages.

- Initial smolt size was the single most influential factor determining growth rate in the study cages, accounting for 60-70% of the variance in specific growth rates among study cages. On average, by the middle of September of the first summer, a 40-g smolt would weigh 370 g, a 90-g smolt 513 g, and a 140-g smolt 548 g. By late June of the second summer, a 40-g smolt, on average, weighed 1260 g, a 90-g smolt 1820 g and a 140-g smolt 1920 g.

- Husbandry variables had more influence on growth rates than environmental variables. Temperature (as accumulated degree-days) could account for about 3% of the total variance in growth rate over the first summer, and was not significant over a full year. Effects of dissolved oxygen depressions were not adequately investigated in this study.

- On average, 85% of the fish placed in cages were harvested, with mortalities accounting for 13%, and 2% being unaccounted. Of the 13% mortality, disease accounted for 3%, seals for

2%, smolt entry losses for 3%, and unspecified mortality for 5%.

- Higher unspecified mortalities for double-stocked cages may indicate higher stress levels.

- About 8.3% of male salmon matured sexually prior to harvest, as compared to 0.8% of females. Mean percent maturation for both sexes combined was 4%.

- Five types of deformity were noted in fish harvested from the study cages: lower jaw, upper jaw, spinal curvature, compressed spine, and tail deformity. About 4.5% of all harvested fish exhibited 1 or more deformities. Lower jaw deformities were most prevalent at 3% of all harvested fish inspected. Salmon with lower jaw deformities averaged about 0.6kg less than normal fish from the same batch.

- Loss due to gutting averaged 12.6%.

- For the first year in sea cages, cages that received the greatest unit rations (rations per fish) had the highest growth rates (corrected for smolt size) and the lowest FCR-indicating perhaps that fish in many cages were fed less than "optimum" rations.

- Feed conversion ratios from smolt entry to harvest, in general, were higher the later the fish were harvested. This is probably due to the fact that larger fish have been reported to have poorer feed conversion, and feed conversion may also be poorer in the colder months. The average FCR from smolt entry to harvest was 1.52.

- FCRs tended to be lower, and growth rates better in large plastic circles than in square steel cages. Feeding rate affected FCR more than growth; cages that had feed delivered most rapidly generally had poorer feed conversion.

- Moist feed usage exceeded dry feed usage for the first summer, with dry diets usage surpassing moist in November of the first year.

- Cages receiving larger smolts were harvested earlier on average: a mean of 23.5 mo for 40- to 60-g smolts, decreasing to 20 mo for 120- to 140-g smolts.

- The coefficient of variation in size of smolts placed in the study cages was 10-15%; this increased to 30% on average by the second summer. Most of the increase in cv occurred in the first summer.

- Feed-type and cage-type were the most influential variables in clustering salmon cages. Seventy-m plastic circles had significantly better FCRs than the survey average for all cages.

- Fin conditions of harvested fish were better at colder temperatures, and were better from larger plastic cages, on average.

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Table 1. Kilometers of wind accumulated for each month of 1995 over 16 compass points. Values for all months are summed for each compass point to obtain an annual accumulated vector. Each annual accumulated vector was then divided by the lowest annual accumulated wind vector to produce an annual wind vector index. Wind data from Saint John airport weather reports.

Month	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Dec.	1992	1000	311	325	308	347	382	323	135	16	129	156	679	934	2627	2648	12312
Nov.	723	585	333	354	918	1105	660	637	713	732	239	346	998	992	877	792	11004
Oct.	349	128	115	372	980	766	340	364	1492	1493	556	627	630	691	750	304	9957
Sept.	894	176	6	52	113	126	154	235	1033	2639	650	214	145	192	833	1291	8753
Aug.	841	567	366	110	109	146	218	76	505	1419	533	417	145	373	639	734	7198
July	199	44	26	0	244	338	268	130	1080	2322	795	331	224	54	208	240	6503
June	533	638	344	50	280	228	198	296	1273	1519	645	520	182	38	92	356	7192
May	907	1045	165	101	859	487	318	408	921	1210	689	112	151	163	247	874	8657
Apr.	989	128	186	139	231	250	463	499	448	927	532	254	589	944	1380	1077	9036
Mar.	2761	2082	323	134	380	435	368	308	911	951	514	62	66	69	499	1291	11154
Feb.	1177	750	148	97	858	265	149	185	828	707	466	449	1983	1239	746	471	10989
Jan.	1786	1008	432	594	532	219	52	91	176	631	682	470	650	715	1502	752	10292
Annual Sum	13151	8151	2755	2328	5812	4712	3570	3552	9515	14566	6430	3958	6442	6404	10400	10830	
Index	5.65	3.5	1.18	1	2.5	2.02	1.53	1.52	4.09	6.26	2.76	1.7	2.77	2.75	4.47	4.65	

Table 2. Annual accumulated wind vectors for each site for each of 16 compass points. Units are km * m. The totals from all compass points are divided by 10,000 to produce the final exposure index which is expressed in hundredths of a km^2 (column on far right).

Site	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Index	Ind./10000
49	452	560	5900	260	250	121	122	91	204	376	938	782	554	412	268	372	11662	1.2
17	2599	1330	389	220	700	768	1040	1429	14888	1502	276	170	277	220	805	1023	27636	2.8
60	565	525	2773	1500	1375	909	765	912	3272	9703	2760	850	692	275	447	698	28021	2.8
20	706	525	177	250	3000	2828	2678	7600	4090	4695	1932	1190	1524	1650	1006	930	34781	3.5
92	2542	1750	590	1150	1375	1414	1148	1216	20450	2191	966	340	416	888	1564	3488	41488	4.1
52	678	490	165	120	350	303	337	395	1104	18154	3312	2006	3269	2640	4291	5208	42822	4.3
35	2825	1750	5900	175	375	252	2142	6612	3068	5321	5658	2040	2770	2338	4470	2558	48254	4.8
6	1695	875	295	325	2750	1818	1377	1596	6135	13146	3588	1785	2354	2888	4694	2325	47646	4.8
79	12430	5338	5900	1000	2125	3232	1454	760	1840	4695	897	935	692	619	1118	5115	48150	4.8
39	12148	6825	708	300	2375	656	556	456	1432	3443	1656	425	762	3988	6482	7905	50117	5.0
68	2825	1925	472	300	875	1111	2448	7600	14520	10642	1518	765	1108	1512	5140	4418	57179	5.7
43	1695	1138	1298	1550	3250	10100	7650	7600	2454	4382	5934	4165	4432	550	671	698	57567	5.8
26	3672	6125	2360	825	562	404	306	418	1840	6104	5520	1955	4018	3712	8718	4999	58990	5.9
1	6498	5250	2065	3000	2875	2020	2372	1976	2658	8764	13800	510	2078	1650	2458	3255	61229	6.1
14	1271	700	206	200	688	505	382	342	3170	21284	11178	3740	5263	7838	22350	2325	81442	8.1
81	3560	2940	1569	1680	12500	3111	2570	3405	14029	31300	3188	1479	1551	1348	2503	2930	89663	9.0
80	28250	11900	212	200	700	768	765	517	982	2254	1159	5304	9252	2695	20115	12834	97907	9.8
13	7514	3185	909	770	12500	10100	1178	7600	8589	20157	3671	2023	3102	6352	17522	23250	128422	12.8
41	18080	9275	4602	3700	12500	1919	7650	7600	20450	31300	8004	3740	4570	5225	11846	23018	173479	17.3
66	28250	17500	2714	600	875	354	306	380	818	818	483	8500	13850	13750	22350	23250	234798	23.5

Table 3. Environmental variables for each of the 20 farms in the study. Max.T: maximum daily mean temperature. Min T: minimum daily mean temperature; cum.d-d: cumulative growing degree-days (above 2°C); cur.speed: mean current velocity ($cm \cdot s^{-1}$); wat.dis.: water displacement in km (see text for definition) over 24 h; exp: exposure index; depth in m.

Farm#	max.T.	min.T	cum.d-d	cur.speed	wat.dis.	depth	exp
1	13.0	1.4	2214	7.0	1.4	(20)11	6.1
6	13.2	1.2	2245	7.4	4.1	16	4.8
13	13.0	1.0	2133	2.7	1.4	9.6	12.8
14	12.4	1.4	2116	9.9	5.7	16	8.1
17	12.6	1.0	2184	5.7	2.0	8	2.8
20	13.4	0.7	2180	2.6	1.1	8	3.5
26	13.2	1.1	2243	17.6	11.0	18	5.9
35	12.4	1.5	2165	12.1	6.8	15	4.8
39	13.3	1.2	2211	9.3	7.2	13	5.0
41	15.2	0.5	2366	4.4	1.5	11	17.3
43	12.9	1.4	2156	12.4	4.3	20	5.8
49	12.4	1.1	2120	3.4	1.9	8	1.2
52	12.0	1.5	2103	11.3	3.0	10	4.3
60	13.5	0.9	2275	6.5	2.6	16	2.8
66	14.2	1.0	2323	5.8	0.9	25	23.5
68	13.1	1.2	2274	5.8	4.3	10	5.7
79	13.2	1.0	2233	6.8	2.8	16	4.8
80	12.5	1.5	2148	7.3	2.0	8	9.8
81	12.1	1.2	2181	9.8	4.6	9	9.0
92	12.5	1.5	2154	9.7	6.6	10	4.1

Table 4. Statistical Parameters of Discriminant Functions derived for the various salmon farm clusters.

Function	Eigenvalue	% variance	Cum.%	Canonical Correlation	Wilks' lambda
1	13.31815	47.28	47.28	0.964447	0.00446
2	7.91692	28.11	75.39	0.94226	0.03985
3	4.37253	15.52	90.91	0.902146	0.21412
4	2.00666	7.12	98.04	0.816948	0.6438
5	0.55326	1.96	100	0.596819	

Table 5. Pooled within-groups canonical correlations between discriminating variables and canonical discriminant functions.

Variable	Func.1	Func.2	Func.3	Func.4
Cum. d-d	0.5058*	-0.4687	-0.09129	0.36951
Min.T.	-0.11141	0.76369*	-0.15881	-0.00262
Max.T.	0.44827	-0.6499*	-0.01169	-0.02014
Current	0.25581	0.64695*	0.40255	0.28684
Expos.	-0.37116	0.18724	0.34707	0.68287*
Displace.	0.12804	0.30861	0.35188	0.47013*
Depth	0.29067	0.09026	-0.29146	0.22595

Table 6. Characteristics of smolts sampled. D: dorsal fin; P: paired fins; C: caudal fin; Op: operculum. Fins were scored from 0 (perfect fin) to 3 (no fin). Fin conditions are means for the sample. Morts are deaths resulting from 96-h exposure to 37 ppt salinity. f male: proportion of smolts sampled that were male; f precoc.: fraction of males sexually precocious; f adh: fraction of sample showing peritoneal adhesions. Standard deviations in parentheses. *: smolts initially placed in incorrect salinity; **: smolts not starved prior to transit; ***: extensive scale loss in transit

		Fin Condition											
Site	Cage	D	P	C	Op.	Sum	Avg.L	Avg.Wt.	Morts	f male	f precoc.	f adh	N
6	S1	0.21	0.02	0.06	0	0.29	23.5(4.0)	131.9(56.0)	0	0.40	0	0.50	52
14	P4	0.20	0	0.10	0	0.30	19.7(2.0)	84.9(23.8)	0	0.60	0	0	30
68	AA2	0.37	0	0.01	0	0.38	20.5(3.6)	84.7(44.2)	2	0.40	0.50	0.20	52
1	35	0.28	0.05	0.05	0	0.38	23.4(2.4)	140.0(24.8)	0	0.50	0	0	20
14	P1	0.35	0.03	0.03	0	0.41	19.6(2.6)	60.8(24.4)	0	0.60	0.17	0.35	20
35	1,2,3	0.30	0.11	0.10	0	0.51	20.6(2.2)	80.7(28.6)	0	0.50	0.03	0.37	60
68	AA6	0.34	0	0.18	0.04	0.56	18.7(5.0)	63.9(24.2)	3	0.60	0.10	0.20	62
92	2	0.65		0	0	0.65	19.4(2.2)	82.1(22.0)	0	0.50	0.03	0	20
60	26	0.30	0.05	0.35	0.05	0.75	19.8(3.4)	82.1(37.6)	6*	0.50	0	0.20	20
79	18	0.55	0.15	0.05	0.03	0.78	23.7(2.6)	126.2(38.0)	1	0.60	0	0.45	20
17	4123	0.81	0	0	0	0.81	25.0(3.4)	188.9(57.0)	8**	0.24	0.05	0	20
1	31	0.68	0.10	0.05	0	0.83	23.5(2.4)	132.2(44.0)	1	0.65	0.10	0	20
26	25	0.78	0	0.05	0	0.83	19.9(2.0)	87.4(28.8)	0	0.35	0.14	0	20
66	6	0.40	0.35	0.10	0	0.85	20.9(3.4)	89.1(18.8)	5	0.70	0	0.20	20
41	2	0.70	0.05	0	0.10	0.85	17.2(2.4)	57.1(16.4)	0	0.65	0.62	0.30	20
92	6	0.73	0.05	0.08	0	0.86	22.6(1.8)	127.7(27.0)	0	0.40	0	0	20
39	15?	0.61	0.26	0.03	0	0.90	24.2(2.4)	166.5(43.0)	3	0.19	0.17	0	31
81	3A	0.48	0.48	0.05	0	1.01	21.0(5.0)	117.5(69.0)	10***	0.62	0.05	0	21
81	5A	0.60	0.15	0.25	0.02	1.02	22.9(1.9)	107.4(25.0)	1	0.35	0	0.25	20
39	14	0.33	0.07	0.67	0	1.07	19.9(2.2)	76.6(24.8)	_	0.67	0.50	0	15
66	4	0.88	0.03	0.15	0.03	1.09	23.9(1.8)	138.7(28.0)	0	0.10	0	0.05	20
20	6F	1.00	0.05	0	0.05	1.10	18.6(1.6)	69.7(18.6)	2	0.65	0.08	0	20
79	16	0.60	0.53	0	0	1.13	21.0(1.6)	100.7(20.0)	1	0.30	0	0.30	20
1	36	1.05	0.05	0.05	0	1.15	18.4(2.2)	70.6(15.6)	0	0.55	0	0	20
26	34	1.13	0.05	0	0	1.18	21.0(2.6)	97.0(31.2)	6*	0.50	0.10	0.20	20
80	4,5	0.85	0.13	0.13	0.08	1.19	18.5(1.8)	63.7(18.2)	1	0.60	0.02	0.05	40
49	22	1.19	0	0	0	1.19	17.2(1.4)	52.0(10.2)	0	0.60	0.17	0	16
49	12	0.89	0.26	0.03	0.03	1.21	21.4(1.4)	99.4(18.8)	0	0.58	0	0	19
41	12	0.90	0.08	0.20	0.05	1.23	22.3(1.6)	108.1(21.0)	0	0.30	0	0.45	20
49	18	1.03	0.18	0.06	0	1.27	19.7(1.8)	77.2(14.8)	0	0.58	0.06	0	17
17	4206	1.00	0.28	0	0	1.28	16.8(1.4)	48.9(14.6)	0	0.40	0	0.05	20
20	3F	1.05	0	0.23	0.03	1.31	20.1(2.4)	83.6(35.2)	0	0.55	0	0.30	20
80	3	1.15	0.20	0	0	1.35	21.8(2.0)	103(27.4)	1	0.30	0	0	20
60	7	1.10	0.30	0	0	1.40	19.9(1.8)	86.8(12.6)	0	0.55	0	0	20
17	4208	0.90	0.10	0.30	0.10	1.40	20.7(2.4)	100(30.2)	2*	0.25	0	0	20
60	21	1.23	0.10	0.08	0	1.41	18.8(2.4)	62.6(29.0)	0	0.55	0.36	0.05	20
52	23	1.03	0.39	0	0	1.42	22.3(3.4)	116.4(26.0)	0	0.84	0.56	0.21	20
52	8	1.05	0.36	0.07	0	1.48	20.7(2.8)	78.0(20.4)	0	0.62	0.31	0.29	20
66	2?	1.10	0.35	0.20	0	1.65	22.4(2.2)	113.8(22.0)	0	0.55	0.09	0.15	20
81	1A	1.33	0.30	0.03	0.10	1.76	20.1(2.0)	83.0(21.4)	2	0.65	0.08	0.10	20
13	B	1.43	0.50	0	0	1.93	18.8(2.1)	83.3(27.0)	0	0.55	0	0.07	30
39	1	1.70	0	0.20	0.03	1.93	19.3(2.4)	76.1(30.8)	_	0.53	0	0.07	15
92	1	1.53	0.43	0.08	0	2.04	16.1(1.4)	39.6(8.2)	10	0.70	0.21	0.05	20

Table 6 (cont'd)

Site	Cage	Fin Condition D	P	C	Op	Sum	Avg.L	Avg.Wt.	Morts	f male	f precoc.	f adh	n
13	C	1.63	0.47	0	0	2.10	16.6(1.2)	48.1(12.2)	4	0.94	0	0.16	30
79	39	1.73	0.40	0	0	2.13	16.6(2.0)	47.8(15.8)	7	0.30	0	0	20
20	1G	0.93	1.00	0.25	0	2.18	25.8(2.4)	214.6(54.0)	0	0.60	0.67	0	20
52	12	0.85	1.25	0.33	0	2.43	23.4(2.8)	128.9(36.0)	3	0.80	0.06	0.10	20
26	23	1.58	0.98	0.43	0	2.99	16.7(1.5)	47.8(9.8)	1	0.75	0.07	0	20

Table 7. Fin condition residuals for various hatcheries. N indicates number of samples (usually 20 smolts per sample).

Hatchery	Fin Res.	N
1	0.02	8
2	0.30	6
3	0.05	11
4*	-0.24	3
5	0.24	4
6	-0.81	3
7*	-0.56	3
8	0.57	2
9	-0.18	2
10	1.19	1
11	-0.20	1
12	0.17	1
13	-0.18	1
14	-0.13	1
15	-0.25	1

* indicates recirculation hatchery.

Table 8. Proportion of male smolts in different size categories.

Length Category(cm)		Proportion of male	N	
S1				
	<15	0.62	8	
	15-17	0.61	103	
	17-19	0.60	203	
	19-21	0.49	294	
	21-23	0.44	206	
	23-25	0.33	123	
	0.25	0.36	28	
	Overall	0.49	965	(474males,491females)
S2				
	<22	0.75	8	
	22-24	0.83	24	
	24-26	0.78	18	
	>26	0.44	9	
	Overall	0.75	59	(44males,15females)

Table 9. Swimming velocity residuals (res.) with cage size and type. Mean res.: Average difference between the mean swimming speeds of fish in each category and the overall mean of 43.9 cm/s. n: number of cages. Each sample is the mean of 10 velocity determinations. Chi^2 tests ratio of negative to positive residuals.

	Cage surface area (m^2)					Cage type	
	0-100	>100/200	>200/300	>300/400	>400	Circ.	Square
n	9	27	22	0	37	55	40
mean res.	1.43	-0.7	-9.9	_	1.76	2.56	-5.58
neg.res.	5	19	20	_	19	29	33
pos.res.	4	8	2	_	18	26	7
chi^2	0.11	3.85	14.73	_	0.02	0.02	8.45
p	<.9	0.05	<.001	_	<.9	<.9	<.005

Table 10. Swimming velocity residuals for various water current regimes. Neg. res: # of negative residuals. Pos. res.: number of Positive residuals. Chi^2 tests ratio of neg. to pos. residuals.

	Average current velocity (cm/s)					
	0 -3	>3 - 6	>6 - 9	>9 - 12	>12 - 15	>15
n	15	16	23	26	12	3
mean res.	-10.2	5.9	-3.6	0.8	-0.2	15.9
neg.res.	15	7	18	15	7	1
pos.res.	0	9	5	11	5	2
chi2	7.54	0.25	3.68	0.62	0.33	0.33
p	<.01	<.9	<.1	<.5	<.9	<.9

Table 11. Swimming velocity residuals vs cage type and water current velocities. Chi^2 tests ratio of negative to positive residuals.

		Current Velocities(cm/s)		
Cage type		0 -6	>6 - 12	>12
Circ.	neg.res.	8	18	3
	pos.res.	4	16	6
	chi2	1.33	0.12	1
	p	<.1	<.5	<.5
Square	neg.res.	13	15	5
	pos.res.	2	4	1
	chi2	4.03	3.18	2.67
	p	<.025	<.1	<.5

Table 12. Weights (g) determined by video tape analysis for the surveyed cages in the first summer. S: smolt size category (g). Each weight is the mean of 100 fish, 50 from each of two levels in the cage.

	Time Measured (Julian Day)												
S	195-200	201-205	206-210	211-215	216-220	221-225	226-230	231-235	236-240	241-245	246-250	251-255	256-260	261-265
40-45														
46-50	109				211								334	
51-55			152								422			451
56-60				212									419	
61-65		144	136	163		246				321,325				
66-70				274										
71-75		172				300		270	255					
76-80										296,330			429,374	
81-85			160	168			261,269						386	569,537
							265							
86-90	165		199,207	208			309	306		341				
91-95														
96-100	189										449		413	
101-105					197					338				
106-110				300										580
111-115							255							
116-120													486	560
121-125														
126-130					298								587,449	
131-135		256				412			434					
136-140							389		408					
211-215								680						

Table 13. Calculated mean specific growth rates (g in %/d), based on weights of previous table

Smolt wt.	Time when Fish were Measured (Julian Day)													
	196-200	201-205	206-210	211-215	216-220	221-225	226-230	231-235	236-240	241-245	246-250	251-255	256-260	261-265
40-45														
46-50	1.01				1.53								1.71	
51-55			1.29	1.34							1.78			1.54
56-60													1.45	
61-65		1	0.9	1.26		1.28				1.45,1.46				
66-70				1.41				1.25						
71-75		1.01				1.32			0.96					
76-80										1.41,1.31			1.19,1.15	
81-85			0.66	0.86		1.31,1.33		1.09					1.05	1.33,1.25
						1.35								
86-90	0.78		1.00,1.05	1.05			1.17			1.31				
91-95														
96-100	1										1.27		0.99	
101-105					0.66					1.05				
106-110				1.22										1.38
111-115							0.88							
116-120													1.05	1.09
121-125														
126-130					1.05								1.11,.86	
131-135		0.75				1.05			0.91					
136-140							0.97		0.81					
211-215								0.94						

Table 14. Predicted G values and weights (Wt) for smolts (S) of various sizes (grams) at 430 days.

S	40	50	60	70	80	90	100	110	120	130	140
G	.803	.781	.760	.739	.719	.699	.680	.662	.644	.626	.609
Wt	1264	1437	1576	1679	1761	1818	1862	1895	1914	1918	1920

Table 15. Summary of mortalities on monitored farms (14 of 20 farms).

Total smolt entry	Moved to unmonitored cage	Total monitored fish	Total harvested(%)
646721	(-)87475	559246	475434(85.0%)

Disease (%)	Smolt Entry Loss(%)	Unspecified Mortality (%)	Unaccounted (%)
BKD 2378(.42)	16617(3.0)	27194(4.9)	11531 (2.1)
ISA 8219 (1.5)			
Cold Water 6147(1.1)	Seal Predation (%)		
Vibrio 10 (.002)	11716(2.1)		
Total 16754 (3.0)			

Table 16. Percent mortalities and initial stocking densities.

Single Stocked	Multiple Stocked	t -Test
1.3	3.5	Mean: Single Stocked:4.0
4.2	8.4	Mean: Multiple Stocked:5.2
5.8	8.5	t value: 1.78
5.0	2.4	critical t value: 1.68
7.9	4.2	P: 0.04
6.1	5.1	
2.3	2.1	
2.1	5.7	
6.0	5.0	
3.8	2.4	Note: these are
2.5	3.1	unspecified mortalities
3.7	6.3	
2.3	6.0	
3.4	6.6	
5.0	6.9	
6.5	3.6	
7.1	8.3	
5.4		
1.6		
2.9		
1.4		
2.2		
4.0		

Table 17. Summary of mature fish sampled at processing plants. Expected % mature values are based on average % maturities of 8.3% for males and 0.8% for females.

Smolt Class	40-60g	60-80g	80-100g	100-120g	120-140g	>140g	Total
Non-mature males	313	1012	828	300	342	124	2919
Non-mature females	364	1264	1089	385	624	71	3797
Mature males	11	130	65	11	41	7	265
Mature females	0	10	7	2	11	0	30
Total males	324	1142	893	311	383	131	3184
Total females	364	1274	1096	387	635	71	3827
% males mature	3.4	11.4	7.3	3.5	10.7	5.3	8.3
% females mature	0	0.8	0.6	0.5	1.7	0	0.8
% total mature	1.6	5.8	3.6	1.9	5.1	3.5	4.2
Expected % mature	4.3	4.3	4.2	4.2	3.6	5.4	
% males	47.1	47.3	44.9	44.6	37.6	64.8	45.4
% females	52.9	52.7	55.1	55.4	62.4	35.2	54.6
% males as smolts	61.5	60	49	44	40	75	49
% females as smolts	38.5	40	51	56	60	25	51
Number of cages	7	20	16	6	7	2	58
Number of Samples	14	49	40	14	21	4	142

Table 18. Summary of deformities from fish sampled at processing plants. Source: Processing Plant; #: number of fish sampled; n: number of fish with a particular deformity; f: number of samples in which deformed fish were present. Numbers in parentheses are proportions of either fish (n) or samples (f) with a given deformity. 50 fish per sample.

		Lower jaw		Upper jaw		Both jaws		Scoliosis		Compressed spine		Hole in tail	
Source	#	n	f	n	f	n	f	n	f	n	f	n	f
1	1250	4(.0032)	3(.12)	1(.00080)	1(.04)	1(.0008)	1(.04)	6(.0048)	4(.16)	1(.0008)	1(.04)	1(.0008)	1(.040)
2	1200	100(.083)	24(1.00)	4(.0033)	4(.167)	1(.0008)	1(.042)	3(.0025)	3(.125)	13(.0108)	8(.33)	3(.0025)	2(.083)
3	1100	1(.0009)	1(.045)	1(.0009)	1(.045)	0	0	3(.0027)	3(.136)	0	0	0	0
4	900	1(.0011)	1(.056)	0	0	0	0	7(.0078)	6(.333)	2(.0022)	2(.111)	0	0
5	700	29(.0414)	14(1.00)	1(.0014)	1(.072)	0	0	5(.0071)	3(.214)	0	0	0	0
6	600	48(.08)	12(1.00)	2(.0033)	2(.167)	0	0	0	0	0	0	18(.026)	6(.50)
7	450	18(.04)	8(.889)	4(.0089)	4(.444)	1(.0022)	1(.111)	2(.0044)	2(.222)	4(.0089)	3(.333)	0	0
8	200	0	0	0	0	0	0	0	0	0	0	0	0
9	200	2(.01)	2(1.00)	0	0	0	0	1(.005)	1(.25)	0	0	0	0
10	150	0	0	0	0	0	0	0	0	0	0	0	0
11	100	4(.04)	2(1.000	3(.03)	2(1.00)	0	0	1(.01)	1(.5)	1(.01)	1(.5)	16(.16)	2(1.00)
12	50	0	0	0	0	0	0	0	0	0	0	0	0
13	50	0	0	0	0	0	0	0	0	0	0	0	0
14	50	0	0	0	0	0	0	0	0	0	0	0	0
15	50	1(.02)	1(1.000	0	0	0	0	1(.02)	1(1.00)	0	0	0	0
Total	7050	208(.03)	68(.482)	16(.0023)	15(.106)	3(.0004)	3(.021)	28(.004)	23(.163)	21(.003)	15(.106)	38(.0054)	11(.0780

Table 19. Comparison of mean ungutted and gutted weights (kg) of processed fish. Sample size equals 50 for ungutted weights.

Farm	Cage	Ungutted	Gutted	Difference	% Diff.
1	12	3.31	2.84	-0.47	-14.2
1	8	3.21	2.81	-0.40	-12.5
1	8	3.32	2.89	-0.43	-13.0
1	4	3.32	2.89	-0.43	-10.2
20	4A	4.85	4.19	-0.66	-13.6
20	2D	4.8	4.16	-0.64	-13.3
20	2A	4.99	4.78	-0.21	-4.2
66	2	5.06	4.30	-0.76	-15.0
66	2	4.11	3.80	-0.31	-7.5
66	2	4.66	3.52	-1.14	-24.5
66	2	4.64	3.88	-0.76	-16.4
66	4	5.31	4.61	-0.70	-13.2
66	4	4.70	4.37	-0.33	-7.0
66	6	4.72	4.23	-0.49	-10.4
Mean					-12.65

Table 20. Average monthly unit rations (grams of moisture-free feed per fish). Note - 95% confidence limits are given in parentheses. These are omitted when number of cages is less than 4.

	Smolt size class (grams)						
	40-60	60-80	80-100	100-120	120-140	160	215
No. of cages	6	13	12	5	7	1	1
Month							
Apr 1995	0.1(-)	0.7(-)	2.0(-)	-	2.2(-)	-	2.8
May	27.0(11.1)	24.4(11.1)	25.4(5.4)	15.9(23.8)	50.0(13.2)	12.4	30.0
June	61.6(12.5)	59.5(19.9)	70.2(10.8)	67.7(42.1)	99.2(34.4)	76.0	125.2
July	104.1(20.1)	99.9(20.3)	108.9(16.1)	113.7(33.4)	152.6(46.2)	171.0	217.3
Aug	193.4(55.8)	184.7(29.4)	200.5(27.2)	194.9(19.4)	234.5(85.7)	226.1	310.4
Sept	288.9(58.4)	270.6(46.2)	289.4(39.8)	297.9(31.0)	324.2(50.9)	312.7	341.1
Oct	297.9(64.4)	324.5(56.9)	279.4(71.3)	388.8(113.4)	362.0(62.4)	561.0	452.6
Nov	281.9(62.5)	234.1(43.6)	260.7(48.3)	320.1(68.1)	286.0(43.6)	416.2	209.4
Dec	134.9(78.5)	120.8(26.7)	123.8(32.9)	201.0(50.5)	161.8(34.5)	235.3	175.2
Jan 1996	80.3(53.5)	62.1(20.0)	74.4(29.0)	101.9(50.5)	76.3(48.6)	108.4	46.8
Feb	78.4(48.6)	56.3(16.7)	76.1(34.4)	75.7(23.4)	70.3(29.9)	55.5	47.8
Mar	92.0(34.3)	64.8(14.4)	92.7(26.0)	102.7(32.6)	90.9(23.7)	74.0	57.7
Apr	161.3(50.3)	112.8(19.2)	154.4(40.7)	187.0(70.1)	157.7(58.8)	123.4	148.1
May	391.3(118.2)	274.0(69.3)	292.4(57.8)	369.6(110.2)	329.8(46.0)	282.2	538.7
June	388.6(179.5)	492.8(132.0)	380.2(66.6)	584.8(223.8)	458.5(65.4)	404.1	1050.0
July	649.8(303.8)	765.4(166.6)	671.0(94.1)	919.7(263.7)	692.2(88.8)	784.4	1149.6
Aug	824.8(270.2)	1041.6(201.5)	895.7(136.3)	1041.6(443.6)	964.6(56.0)	1086.3	533.4
Sept	823.1(245.6)	927.2(179.5)	759.6(210.4)	850.6(386.3)	813.1(44.4)	1039.3	282.6
Oct	839.2(391.2)	850.9(266.5)	843.3(244.0)	892.7(915.0)	672.2(331.4)	572.2	274.1
Nov	683.1(243.2)	684.4(233.8)	661.1(218.8)	673.7(200.2)	727.2(397.2)	469.6	-
Dec	369.0(142.2)	431.4(159.3)	389.3(105.5)	318.0(-)	161.2(-)	171.8	-
Jan 1997	230.2(121.0)	181.7(-)	202.0(-)	163.3(-)	-	113.5	-
Feb	134.8(40.9)	126.1(-)	198.7(-)	156.3(-)	-	73.4	-
Mar	203.0(-)	155.5(-)	134.8(-)	161.0(-)	-	27.8	-
Apr	147.8(-)	18.0(-)	195.7(-)	77.1(-)	-	153.5	-
May	382.2(-)	-	442.6(-)	-	-	-	-
June	999.3(-)	-	783.7(-)	-	-	-	-
July	246.4(-)	-	-	-	-	-	-
Mean total unit ration	7492.3	6957.0	7211.4	7504.0	6621.8	7550.1	6092.8
Est. mean harvest wt (undressed)	5271.5	4757.0	4995.6	4977.8	4714.2	4731.0	4080.0

Table 21. Mean unit rations (grams moisture-free feed per fish) for varous growth intervals.

Smolt size class (g)	Time interval									Mean harvest weight			Unit FCR (v.95-harvest)			Mean months to harvest
	v.95 - x.95			v.95-vi.96			v.95-harvest									
	x	n	range	x	n	range	x	n	range	x	n	range	x	n	range	
40-60	973	6	708-1177	2510	6	1780-3207	7197	6	4601-10524	4935	6	4100-6800	1.33	6	1.10-1.51	23.5
60-80	964	13	655-1284	2342	10	1580-3104	6875	8	4597-9036	4757	8	3450-6100	1.46	8	1.07-1.79	22.2
80-100	975	12	564-1278	2443	10	1796-2998	6478	9	5310-8075	4996	9	4362-5683	1.30	9	1.14-1.63	20.6
100-120	1079	5	926-1257	2940	4	2657-3212	6477	4	5650-9300	4893	4	3620-6090	1.49	4	1.30-1.56	20.5
120-140	1225	7	849-1818	2699	6	2818-3635	6962	6	4875-7483	4714	6	3380-5560	1.36	6	1.15-1.47	20.1
160	1359	1		3058	1		7550	1		4731	1		1.51	1		21.5
215	1479	1		3853	1		6093	1		4080	1		1.49	1		16.0

Table 22. Feeding efficiency of surveyed cages relative to survey average. Predicted unit FCR is derived from the regression of Fig. 61. Unit FCR residuals are differences between cage FCRs and predicted FCRs from Fig. 61.

Site	Cage	Total unit ration (g)	Measured unit FCR	Predicted unit FCR*	Unit FCR residual	Mean harvest wt	Smolt size	Mean harvest month
06	S3, S4	6557	1.07	1.37	-0.30	6100	72	Mar 1997
92	2	6310	1.14	1.35	-0.21	5538	82	Feb 1997
79	39	10524	1.49	1.68	-0.19	6800	48	July 1997
66	4	5551	1.15	1.29	-0.14	4836	139	Mar 1997
81	1A	6962	1.27	1.40	-0.13	5478	83	Jan 1997
81	3A	7210	1.30	1.42	-0.12	5538	118	Feb 1997
43	8	6543	1.25	1.37	-0.12	5250	55	Apr 1997
26	23	4601	1.10	1.21	-0.11	4100	48	Mar 1997
92	1	5974	1.21	1.32	-0.11	4935	40	May 1997
66	6	5877	1.21	1.31	-0.10	4868	83	Jan 1997
92	6	7483	1.35	1.44	-0.09	5560	128	Mar 1997
26	25	5310	1.18	1.27	-0.09	4490	87	Feb 1997
66	2	5786	1.24	1.30	-0.06	4673	80	Feb 1997
80	4	4932	1.18	1.24	-0.06	4098	64	Oct 1996
79	16	9300	1.53	1.58	-0.05	6090	101	Mar 1997
06	S5,S10	9036	1.51	1.56	-0.05	6000	62	May 1997
43	10	6477	1.32	1.36	-0.04	4893	90	Nov 1996
06	S1, S6	7353	1.39	1.43	-0.04	5304	132	Sept 1996
26	34	6136	1.31	1.33	-0.02	4688	97	Jan 1997
17	4206	7650	1.44	1.45	-0.01	5320	49	May 1997
01	35	6386	1.38	1.35	+0.03	4630	140	Dec 1996
13	A+B	7892	1.51	1.47	+0.04	5224	48	Jan 1997
13	C+D	6198	1.42	1.34	+0.08	4362	83	Nov 1996
79	18, 14	6721	1.47	1.38	+0.09	4575	126	Jan 1997
52	12	7147	1.51	1.41	+0.10	4731	160	Jan 1997
01	36	4597	1.33	1.21	+0.12	3450	71	Oct 1996
52	7	7260	1.56	1.42	+0.14	4663	116	Jan 1997
17	4208	8075	1.63	1.49	+0.14	4960	100	May 1997
20	1G	6093	1.49	1.33	+0.16	4080	215	Aug 1996
01	31	4875	1.44	1.23	+0.21	3380	132	Oct 1996
20	6F	8629	1.74	1.53	+0.21	4960	70	Feb 1997
20	3F	8719	1.79	1.54	+0.25	4850	76	Jan 1997
80	3	5650	1.56	1.30	+0.26	3620	103	Nov 1996
80	5	6743	1.78	1.38	+0.40	3925	64	Jan 1997

Table 23. Surveyed cages clustered according to husbandry variables. Cage size 4: extra large; 3: medium; 1: small. Cage shape 1: circular; 2: square. Feed type: percent total ration that is moist diet. Feed rate in g moisture-free feed per kg fish per 100 s. Ration in g of moisture-free feed.

Site-cage	Cage size	Smolt size	Feed type	Feed rate1	Feed rate2	Cage shape	Ration (total unit)
				Cluster 1			
66-2	4	80	2.8	0.724	0.378	1	5786
66-6	4	83	2.0	0.920	0.328	1	5877
43-9	4	90	0.45	1.598	0.304	1	6959
81-1A	4	83	8.60	0.967	0.406	1	6962
43-8	4	55	0.51	2.344	0.277	1	6543
43-10	4	90	0.53	2.682	0.384	1	6477
6-s3	4	72	25.3	0.386	0.342	1	6557
13-A	4	83	18.2	0.832	0.860	1	6198
13-B	4	48	13.3	1.082	0.866	1	7892
92-1	4	40	1.50	1.033	0.694	1	9036
				Cluster 2			
1-35	4	140	28.6	0.486	0.836	1	6386
92-6	4	128	0.64	0.668	0.893	1	7483
1-31	4	132	3.9	0.559	0.956	1	4875
66-4	4	139	0.87	0.476	0.333	1	5551
80-3	4	103	2.9	0.759	0.283	1	5650
6-s1	4	132	34.4	0.282	0.235	1	7353
				Cluster 3			
35-1	2	81	50	2.003	0.521	2	9546
35-3	2	81	50	2.171	0.398	2	9150
35-2	2	81	50	1.176	0.884	2	7615
39-14	2	77	80	1.312	0.907	2	5685
39-15	2	87	80	2.112	0.768	2	6308
39-1	2	76	80	1.295	0.800	2	7691
79-18	2	126	100	1.854	0.731	2	6721
				Cluster 4			
52-7	1	116	100	1.996	1.014	1	7260
52-12	1	160	100	1.087	0.998	1	7147
26-23	2	48	93.6	2.338	0.898	1	4601
26-25	2	87	94	1.878	0.469	1	5310
26-34	2	97	91.2	2.075	0.667	1	6136
				Cluster 5			
41-3	3	69	25	1.072	1.436	1	6962
1-36	4	71	0.88	0.773	1.534	1	4597
92-2	4	82	2	1.132	1.652	1	6310
				Cluster 6			
14-P1	4	61	72.7	0.583	0.6	1	7085
14-P4	4	85	71.9	0.477	0.714	1	8074
81-3A	4	118	68.2	0.778	1.305	1	7210

Table 23 cont'd

Site-cage	Cage type	Smolt size	Feed type	Feed rate1	Feed rate2	Cage shape	Ration (total unit)
				Cluster 7			
49-18	1	77	0.5	1.446	1.096	1	5533
49-22	1	52	0.5	1.819	1.183	1	6566
49-12	1	99	0.5	1.169	0.696	1	5107
				Cluster 8			
20-1G	3	215	94.8	1.119	2.007	2	6093
20-3F	3	76	98	2.676	2.773	2	8719
20-6F	3	70	98.4	3.028	2.925	2	8629
81-5A	4	107	100	0.994	2.663	1	8938
				Outliers			
80-4	3	64	24.4	0.761	0.264	1	4932
80-5	3	64	20	1.415	0.246	1	6743
17-4206	3	49	6	1.482	1.313	2	7650
17-4208	2	100	6.6	2.934	2.517	2	8075
79-16	2	101	100	7.91	1.674	2	9300
79-39	2	48	100	6.944	2.764	2	10524

Table 24. Canonical discriminant functions

Fcn.	Eigenvalue	% Variance	Cum. %	Canonical Corr	After Fcn.	Wilks' Lambda	Chi^2	df	Signf.
					0	.00003	348.58	49	.0000
1	27.94	50.89	50.89	.9826	1	.00088	235.85	36	.0000
2	16.28	29.66	80.55	.9706	2	.01514	140.38	25	.0000
3	5.877	10.70	91.25	.9244	3	.10412	75.78	16	.0000
4	4.050	7.38	98.63	.8955	4	.52581	21.535	9	.0105
5	0.4828	0.88	99.51	.5706	5	.77966	8.338	4	.0800
6	0.2230	0.41	99.91	.4270	6	.95352	1.594	1	.2067

Table 25. Correlations between variables and discriminant functions

Variable	Func.1	Func.2	Func.3	Func.4
Cage size	.15486	.87819*	.36126	.08597
Feed Type	.43068*	-.59309*	.22625	.52649
Cage Type	.38920*	-.29312	-.74414*	-.24736
Feed Rate 2	.28137	-.18599	.45397	-.76121*
Smolt Weight	.05056	-.02389	.10018	-.00408
Feed Rate 1	.04984	-.18114	-.04042	-.03203
Total ration	.12155	-.00045	-.07926	.01239

Table 26. Analysis of variance of feeding efficiency for cage type and size. FCR residuals for 70-m circles, smaller circular cages and square cages in first three columns, respectively. Count: number of cages; Sum: summed residuals; Average: average residual.

70-m circ.	smaller c.	square	Anova: Single Factor						
-0.30	-0.11	-0.19							
-0.21	-0.09	-0.05	SUMMARY						
-0.14	-0.06	-0.01	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
-0.13	-0.02	0.09	Column 1	15	-1.39	-0.09267	0.008435		
-0.12	0.1	0.14	Column 2	8	0.62	0.0775	0.033336		
-0.12	0.14	0.16	Column 3	8	0.6	0.075	0.021943		
-0.11	0.26	0.21							
-0.10	0.4	0.25							
-0.09			ANOVA						
-0.06			*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
-0.05			Between Groups	0.220924	2	0.110462	6.124112	0.00622	3.340389
-0.04			Within Groups	0.505043	28	0.018037			
-0.04									
0.04			Total	0.725968	30				
0.08									

Table 27. ANOVA of fin condition comparisons of processed fish from various cage types.

70 m vs Octagonal				
Mean		df	t	P
70 m	Oct.			
2	2.42	95	2.01	0.02

70 m circular vs square				
Mean				
70 m	square	df	t	P
2	2.52	108	3.18	0.001

Octagonal vs Square				
Mean				
Oct.	Square	df	t	P
2.52	2.42	22	0.23	0.4

70 m circular vs 50 m circular				
Mean				
70 m	50 m	df	t	P
2	2.48	93	2.08	0.02

Table 28. Comparisons of fin conditions of mature vs immature fish (t-tests).

	Mean fin cond.					
Farm	Imm.	Mat.	t	P	df	sex
1	1.70	1.61	5.88	0.0004	8	m
14	2.24	1.61	2.61	0.007	27	m
17	1.67	1.64	1.30	0.5	6	m
39	2.17	1.61	1.30	0.11	8	m
43	3.11	2.72	2.24	0.02	22	m
52	2.55	2.67	-0.20	0.4	8	m
66	1.74	0.83	2.56	0.02	8	m
79	3.09	2.68	1.31	0.1	17	m
80	2.70	2.00	3.04	0.005	12	m
81	2.17	1.91	1.18	0.12	26	m
92	1.26	0.10	9.19	0.0004	4	m
pooled	2.21	1.59	2.74	0.006	22	f

Table 29. Comparison of specific growth rates of salmon in sea cages at various sizes (mean temperature of 8°C).

Norway (Austreng et al. 1987)		Our study	
Mean wt. (g)	G	Mean wt. (g)	G
30-150	1.3	130	1.7
150-600	1.0	180	1.4
600-2000	0.6	230	1.2
>2000	0.4	280	1.0

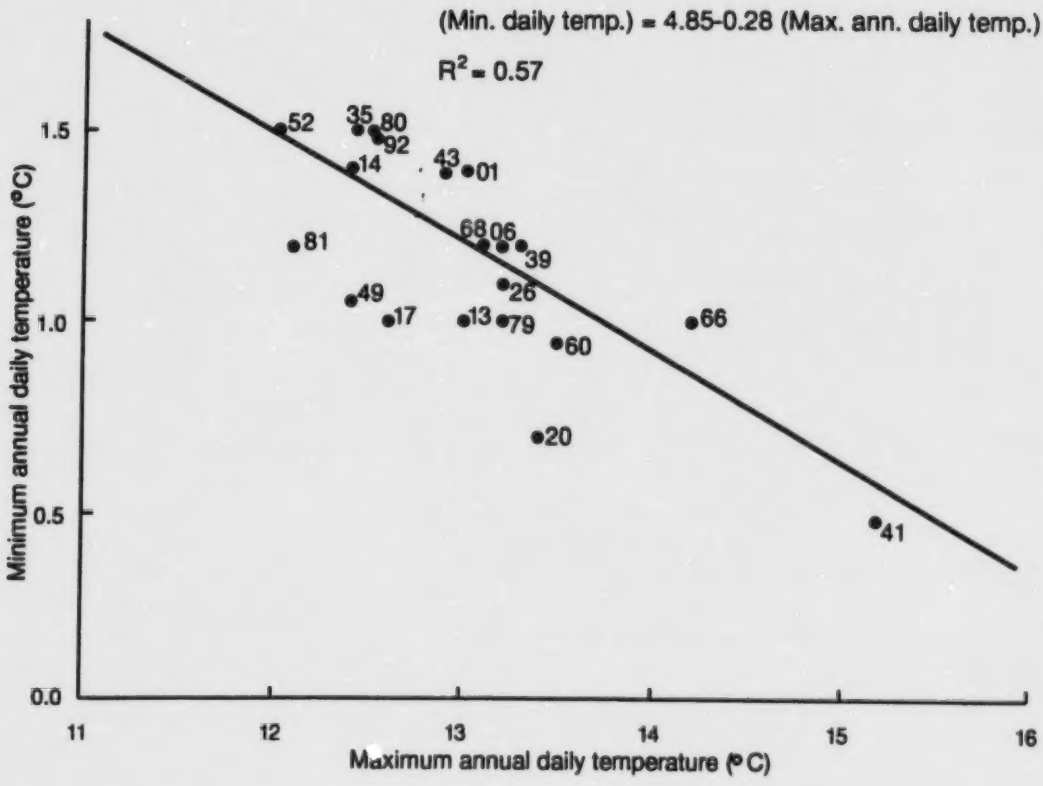


Fig. 1. Minimum annual daily mean temperature for each of 20 farms is plotted against maximum annual daily mean temperature. These values are for May 1, 1995 to April 30, 1996.

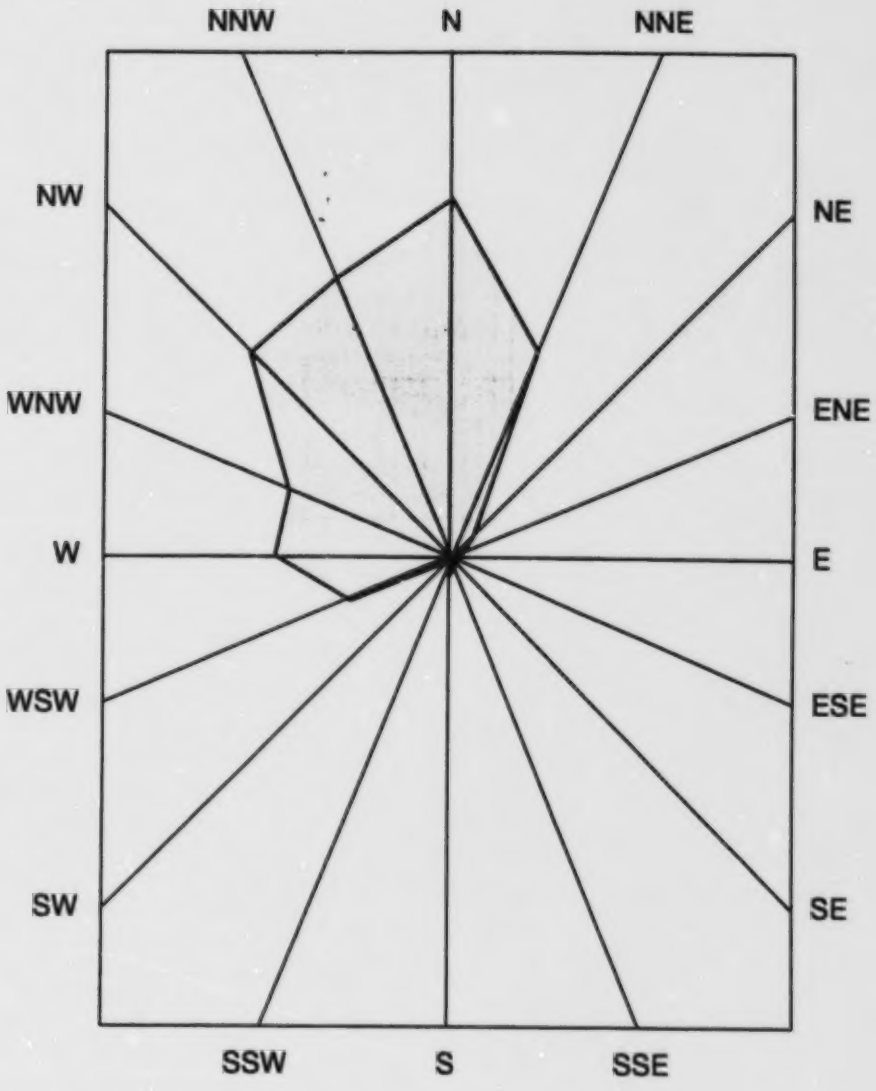


Fig. 2. Exposure profile of farm #66 in the survey. The length of the shaded section along each of the compass directions indicates the amount of exposure (defined in text). 1 cm = 5000 km - m.

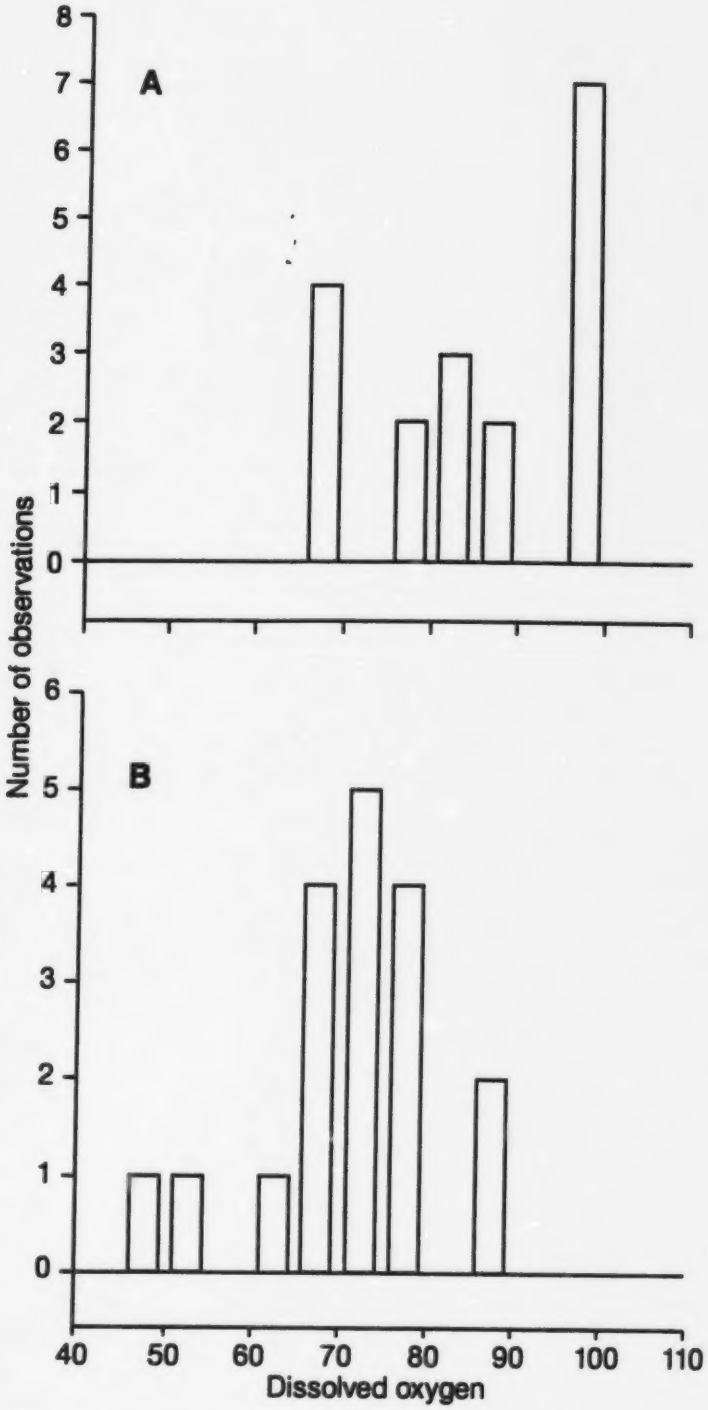


Fig. 3. Maximum (A) and minimum (B) oxygen concentrations (% saturation) measured over a 24-h period in late summer at 18 salmon farms.

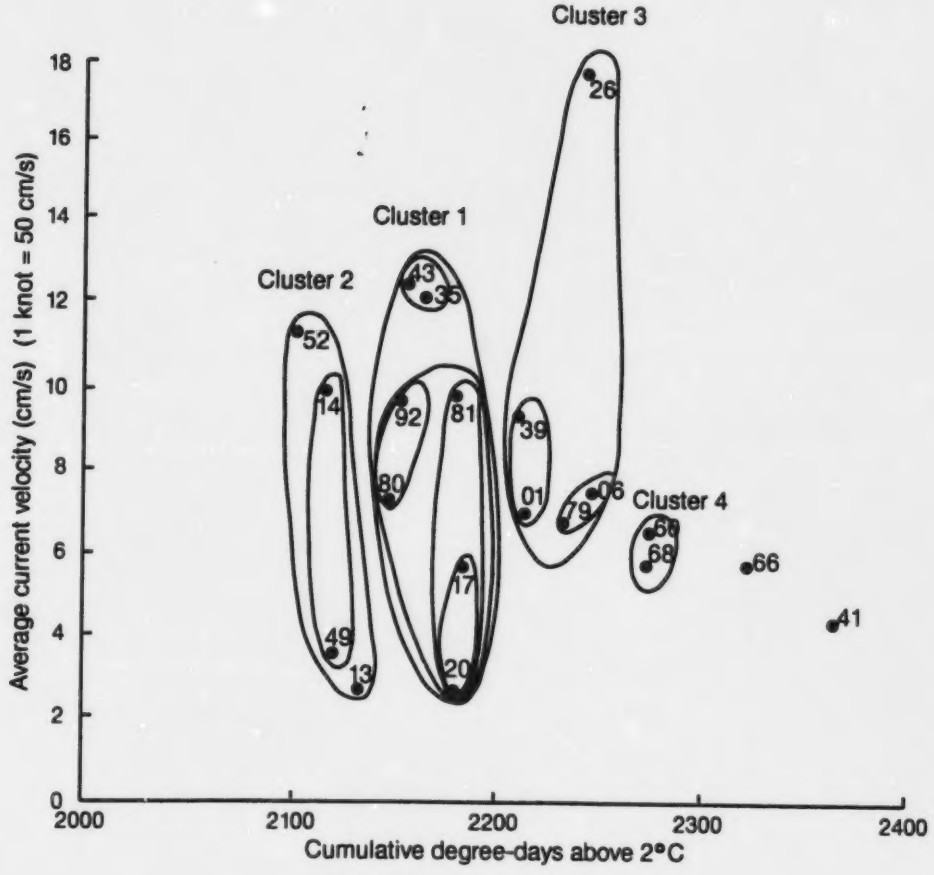


Fig. 4. Salmon farms clustered, based on discriminant function scores using unstandardized physical variables, plotted on a grid of mean current velocity and cumulative degree-days above 2°C. Obviously degree-days account for much of the variance among clusters.

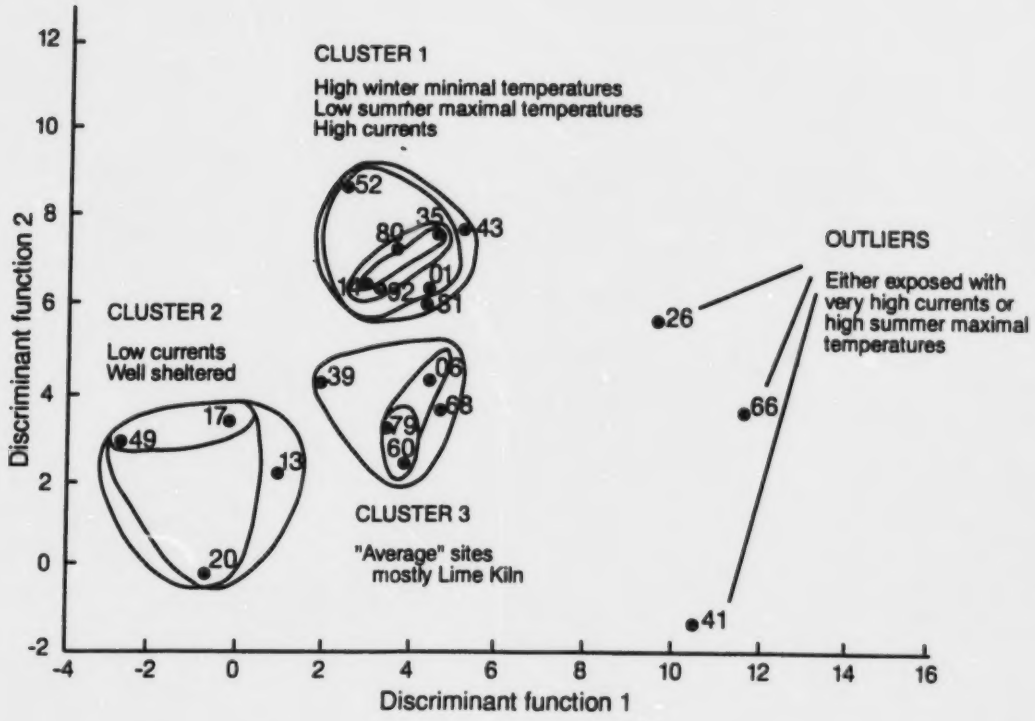


Fig. 5. Salmon farms clustered, based on discriminant function scores using physical variables standardized to equivalent weighting, are plotted on a grid of the first two discriminant functions.

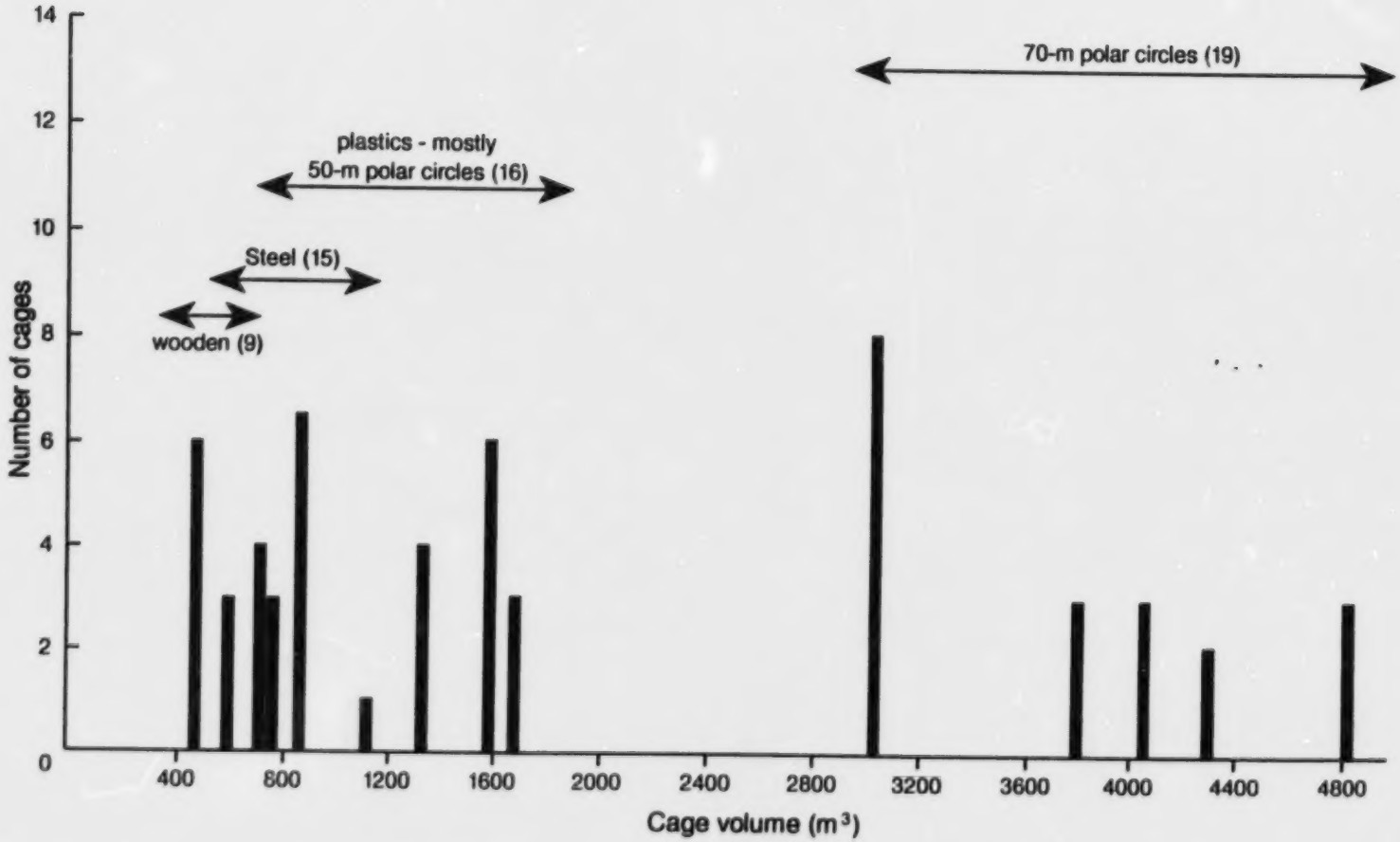


Fig. 6. Frequency distribution of cage types monitored in the survey of salmon farms. Three cages at each of 20 farms were monitored. Numbers in parentheses are number of cages.

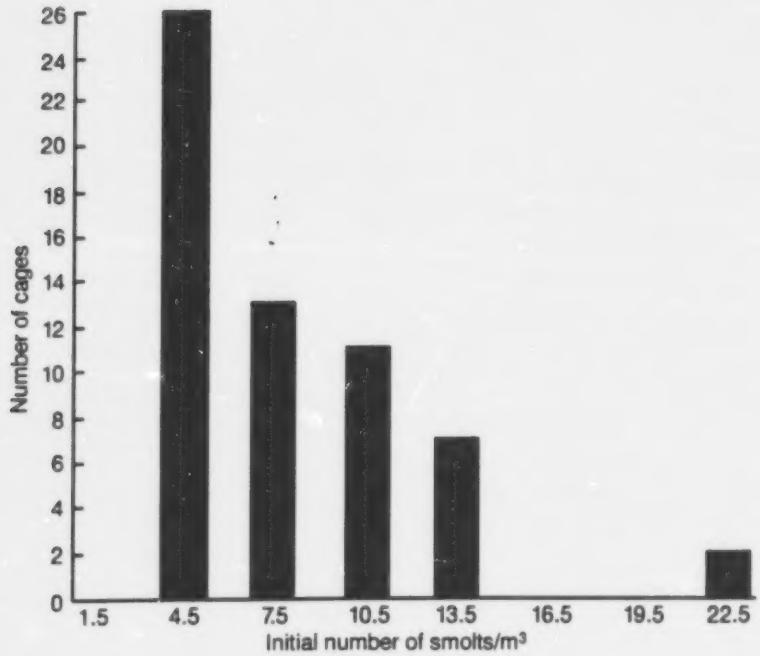


Fig. 7. Frequency distribution of smolt densities stocked in each of the monitored cages. Densities are pooled over ranges of ±1.5 smolts/m^3. For example, the mean of 4.5/m^3 is for densities ranging from 3-6 smolts/m^3.

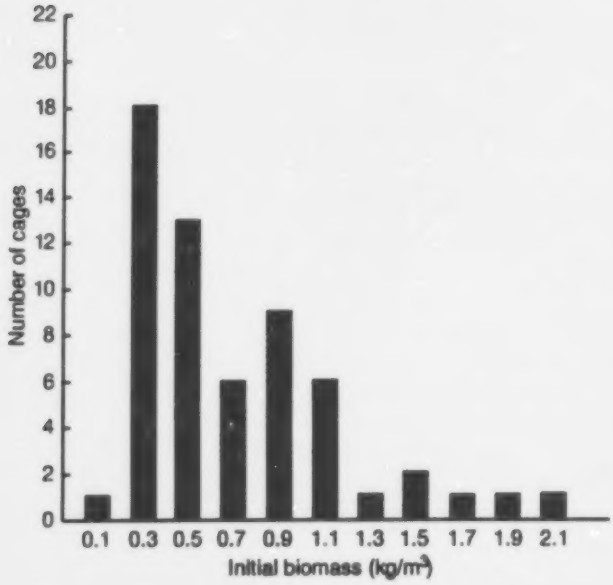


Fig. 8. Frequency distribution of initial biomass densities of smolts stocked in each of the monitored cages.

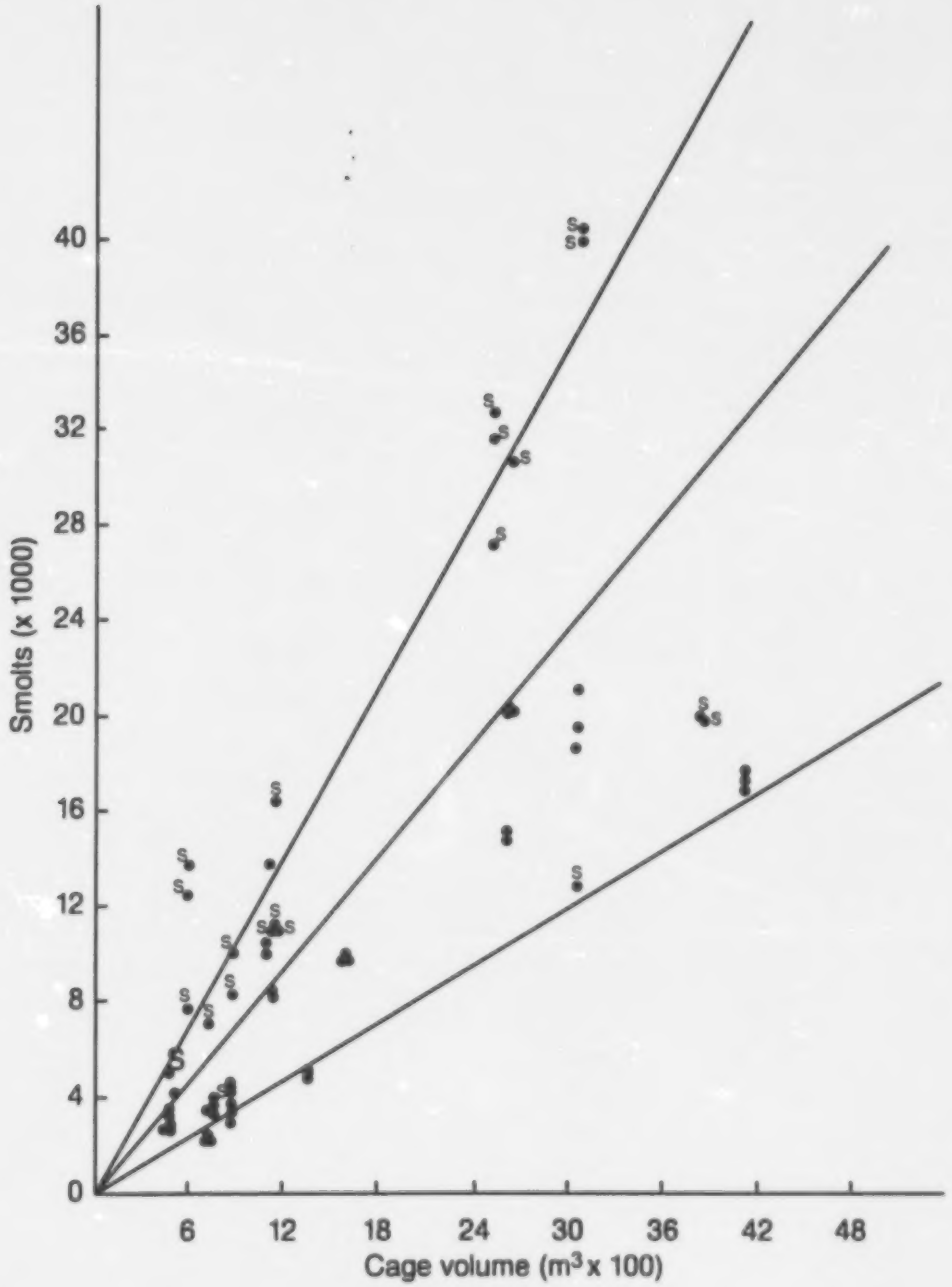


Fig. 9. Smolt stocking density is plotted as a function of cage volume. "S" indicates cages where the smolts will be subsequently divided into 2 or more cages. The 3 lines are reference lines for 3 stocking densities (4, 8. and 12 smolts/m^3.)

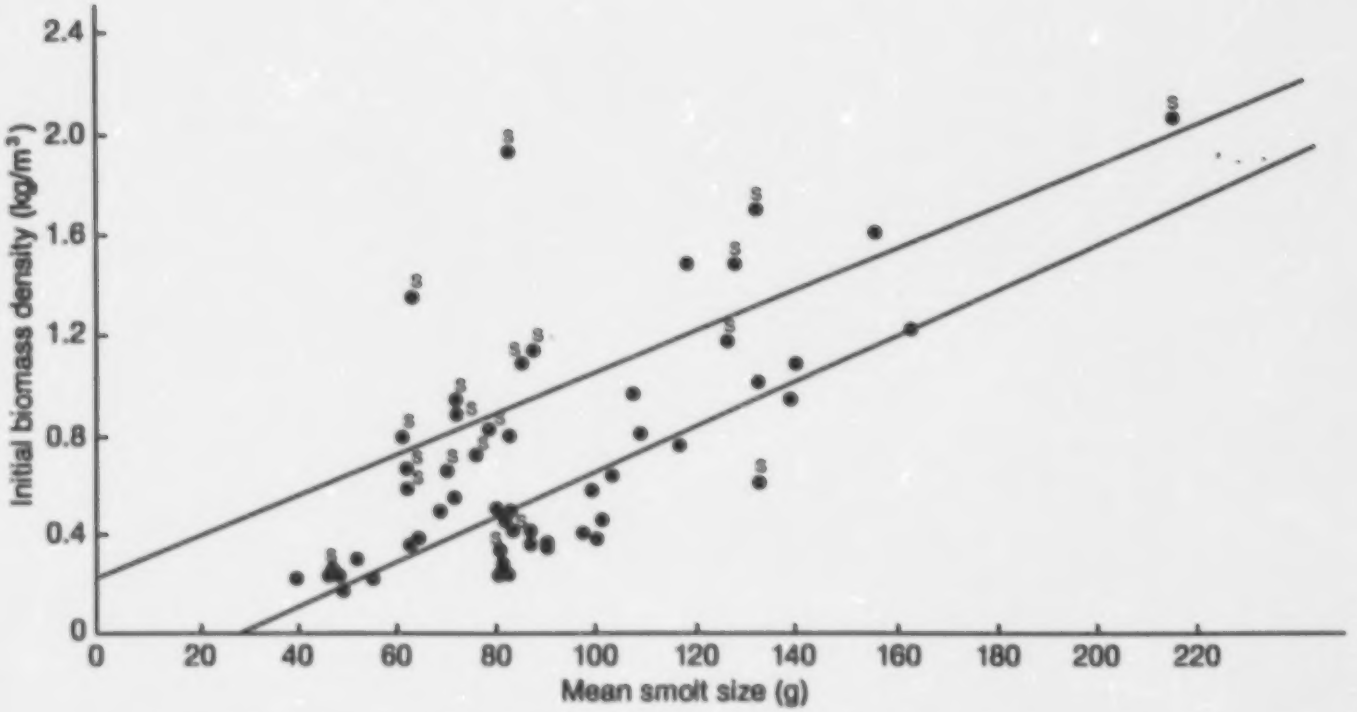


Fig. 10. Initial biomass densities are plotted as a function of mean smolt size; "s" indicates cages where smolts will be later divided among two or more cages. Lines are based on regression of biomass density vs smolt size; upper line for cages to be split. For equations, see text.

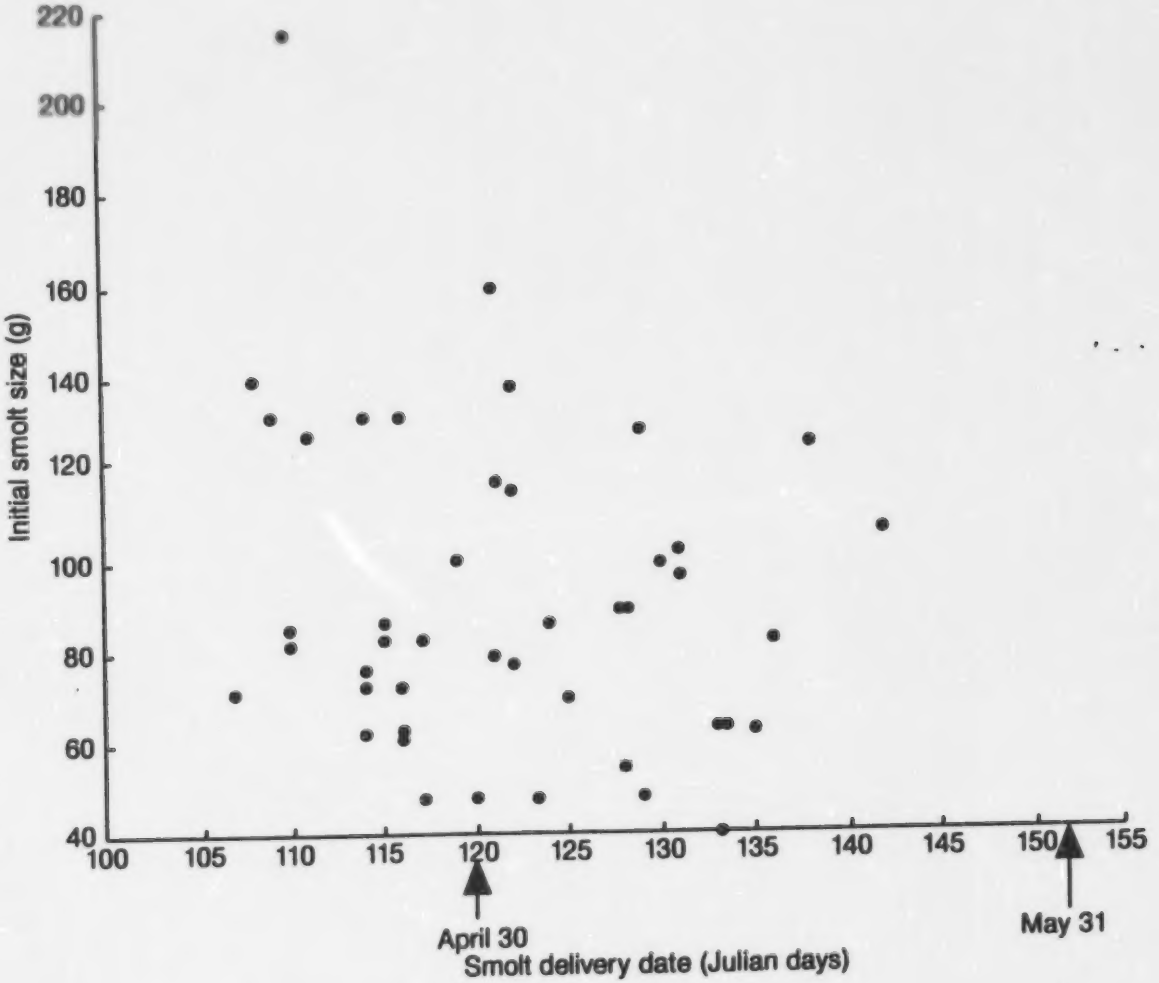


Fig. 11. Smolt delivery dates for smolts of various sizes.

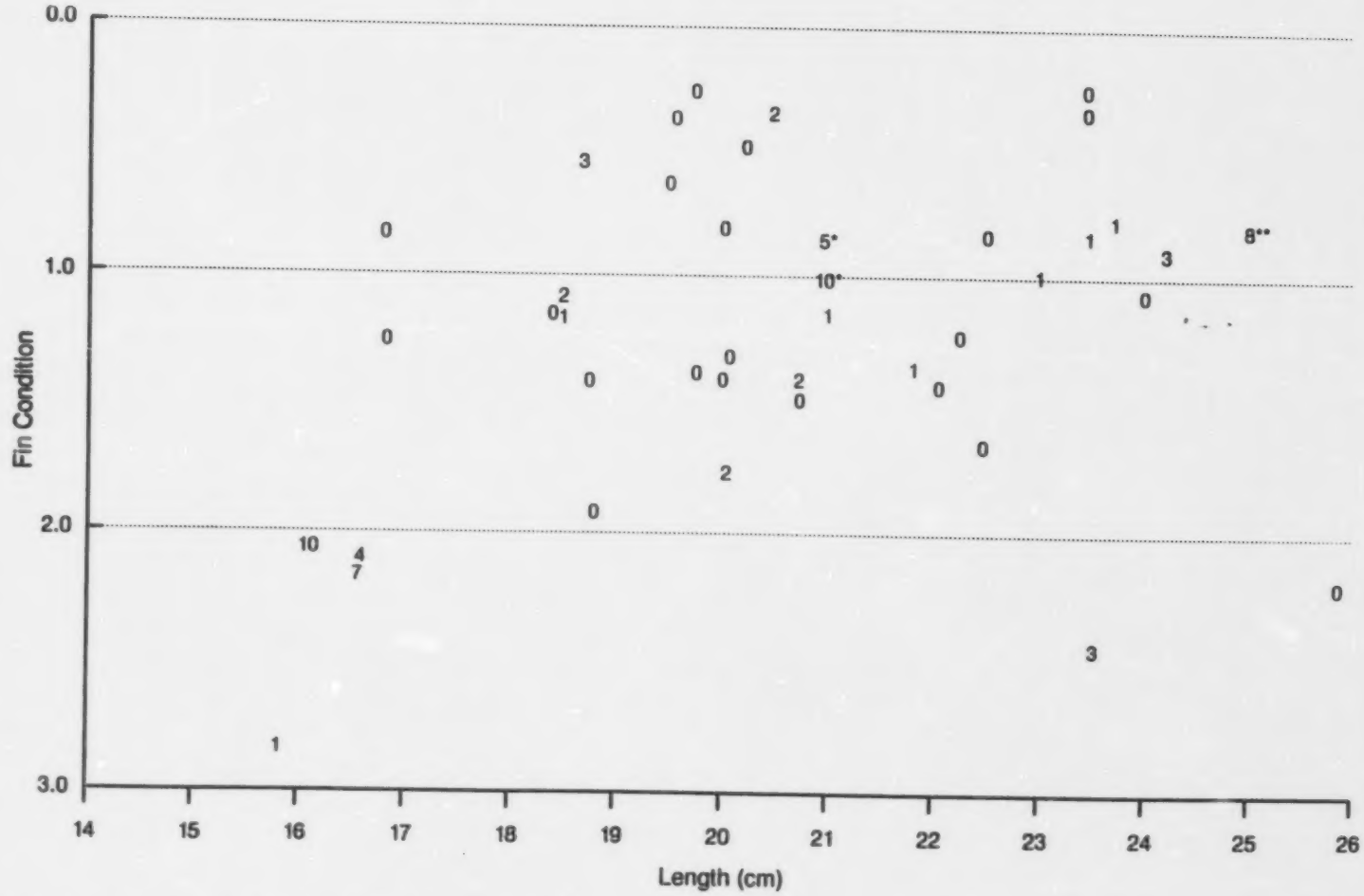


Fig. 12. Number of dead fish out of 10 tested in the salinity challenge shown in relation to their length and fin condition. Two asterisks: smolts not starved prior to transit, one asterisk: significant scale loss in transit.

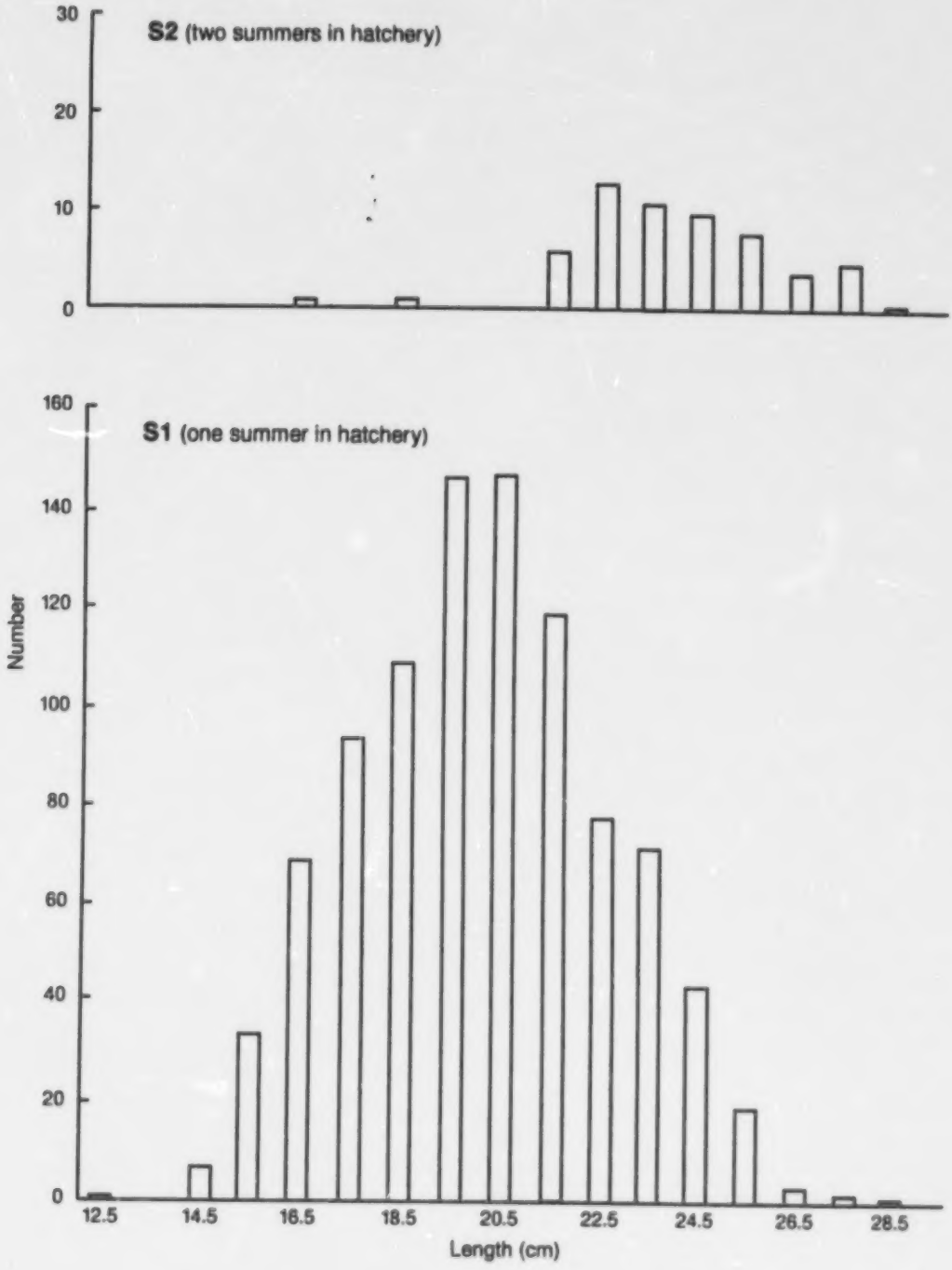


Fig. 13. Frequency distributions of lengths for S2 (upper panel) and S1 (lower panel) smolts.

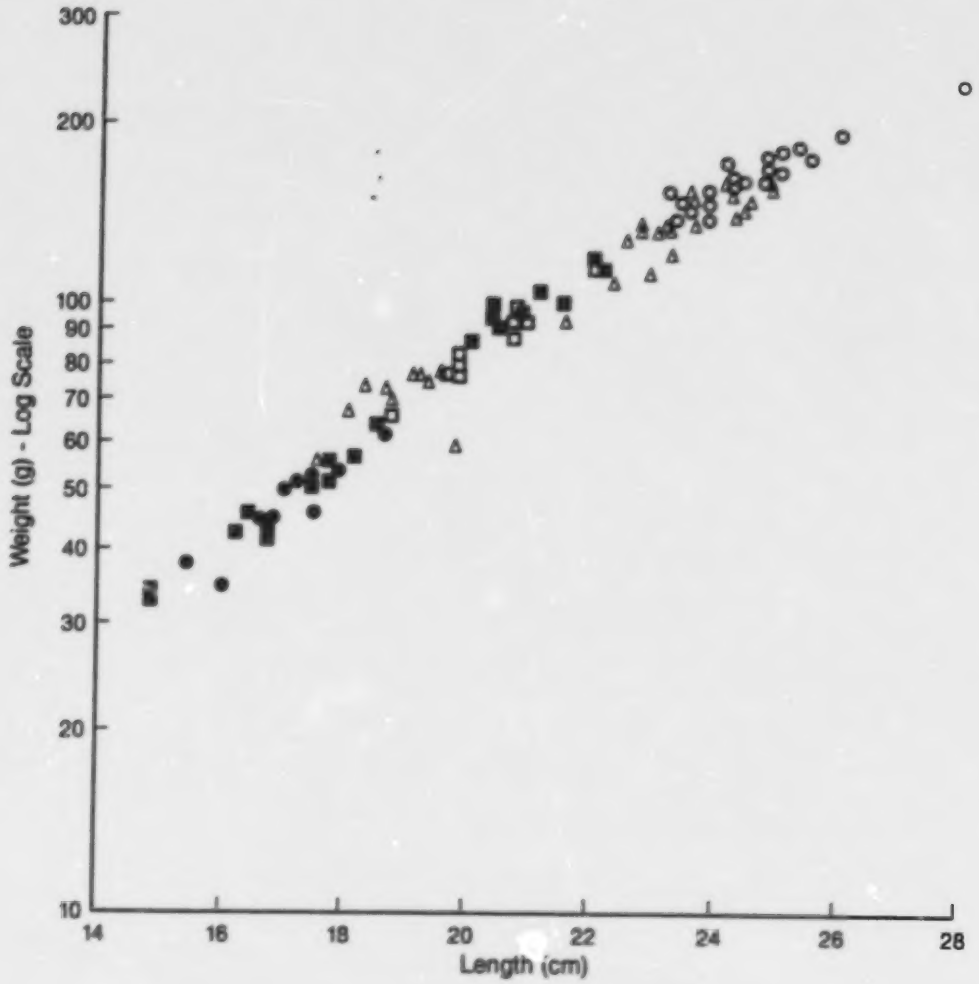


Fig. 14. Weight-length relationships for smolts from 6 hatcheries. Each symbol represents a different hatchery.

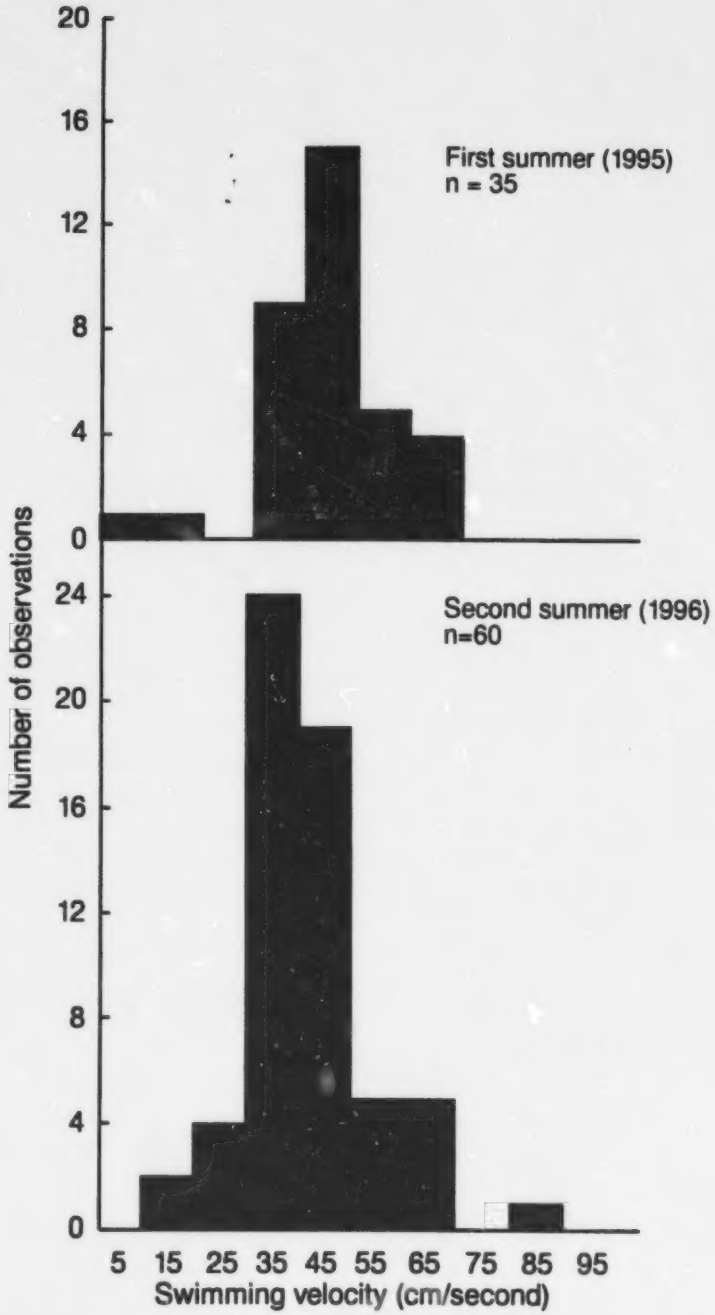


Fig. 15. Frequency distribution of the apparent swimming velocities in cm/s of caged salmon in the first (upper panel) and second (lower panel) summers.

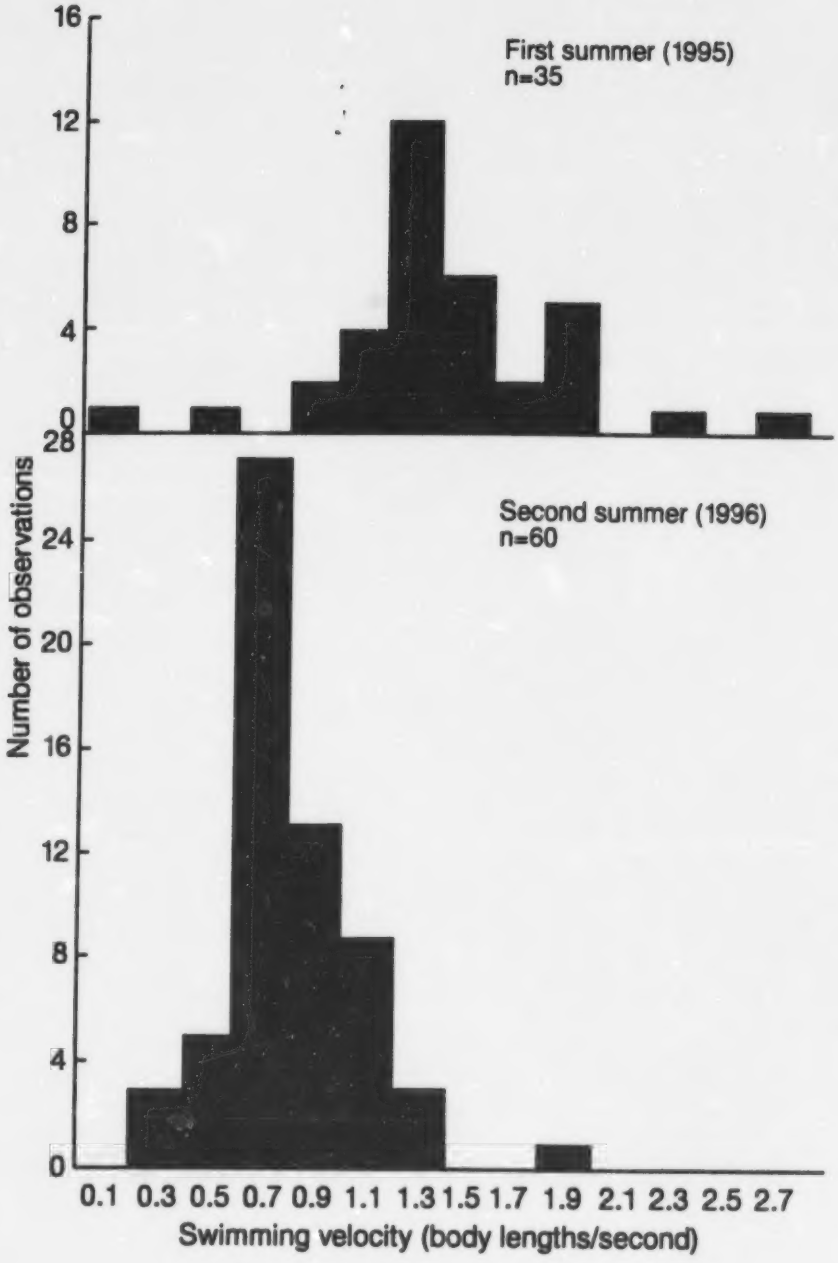


Fig. 16. Frequency distributions of the apparent swimming speed of caged salmon in body lengths/s in the first (upper) and second (lower) summers.

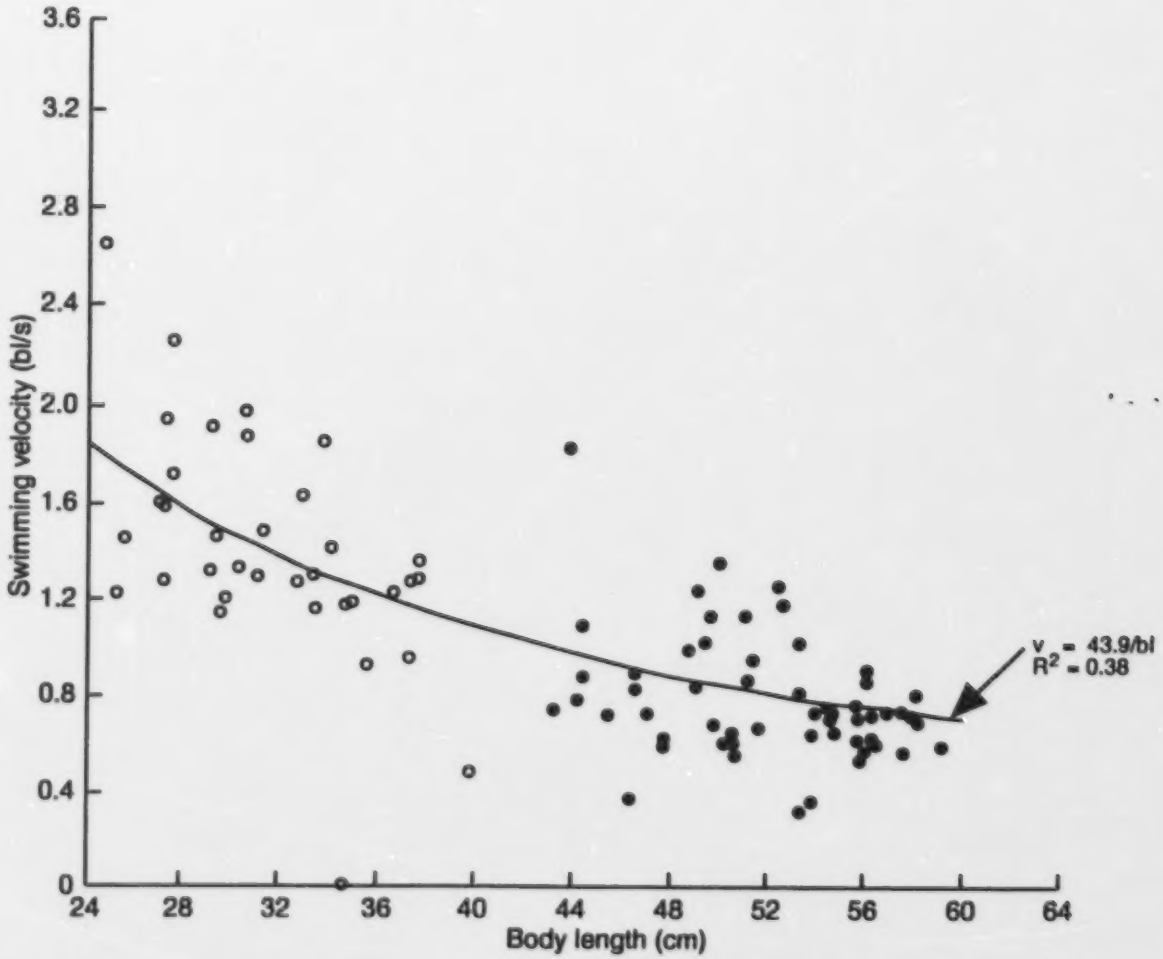


Fig. 17. Swimming velocity of caged salmon (bl/s) as a function of body length. The plotted line is the line of best fit for velocity as a reciprocal of body length. Open circles: first summer's data; closed circles: second summer's data.

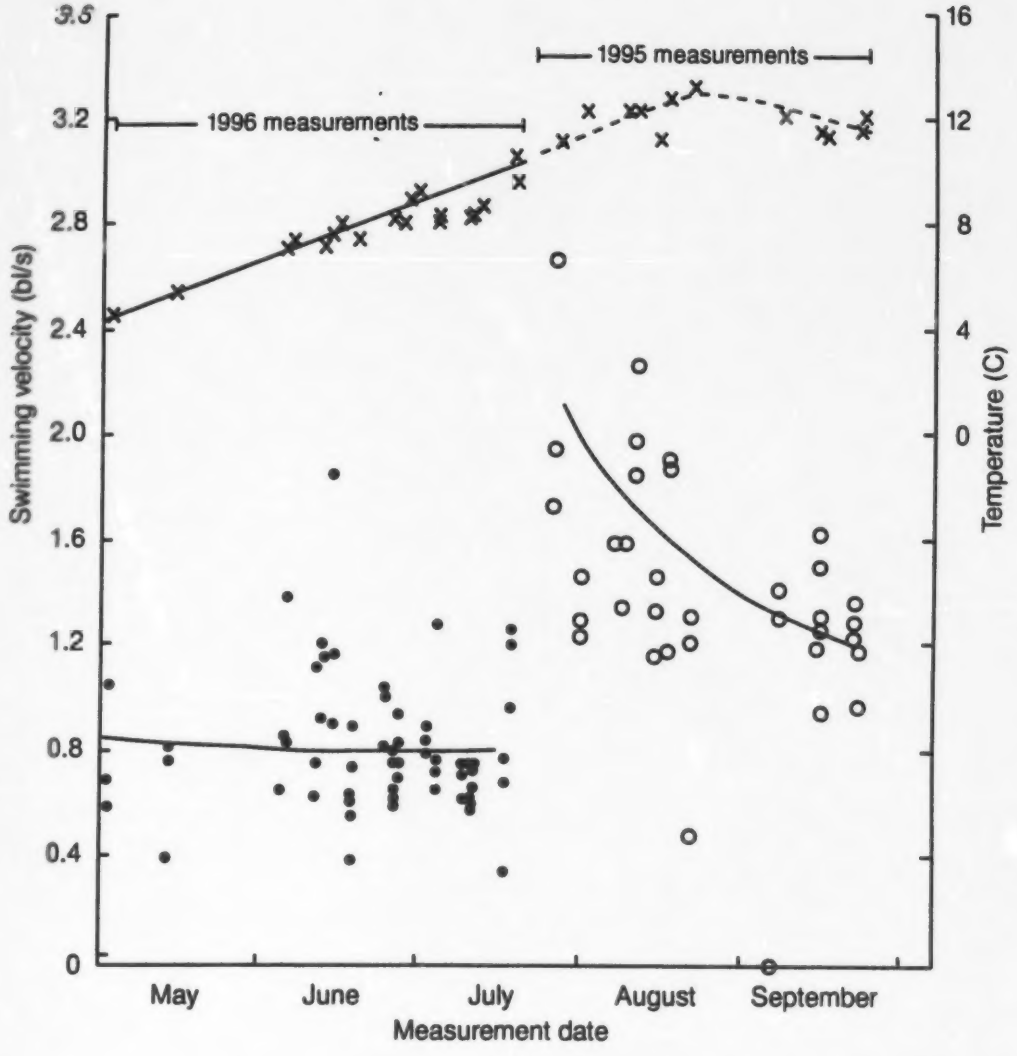


Fig. 18. Swimming velocities as bl/s and cage temperatures for various dates when swimming speeds were measured. Lines fitted by eye. Open circles: first summer; closed circles: second summer; x: temperature (°C).

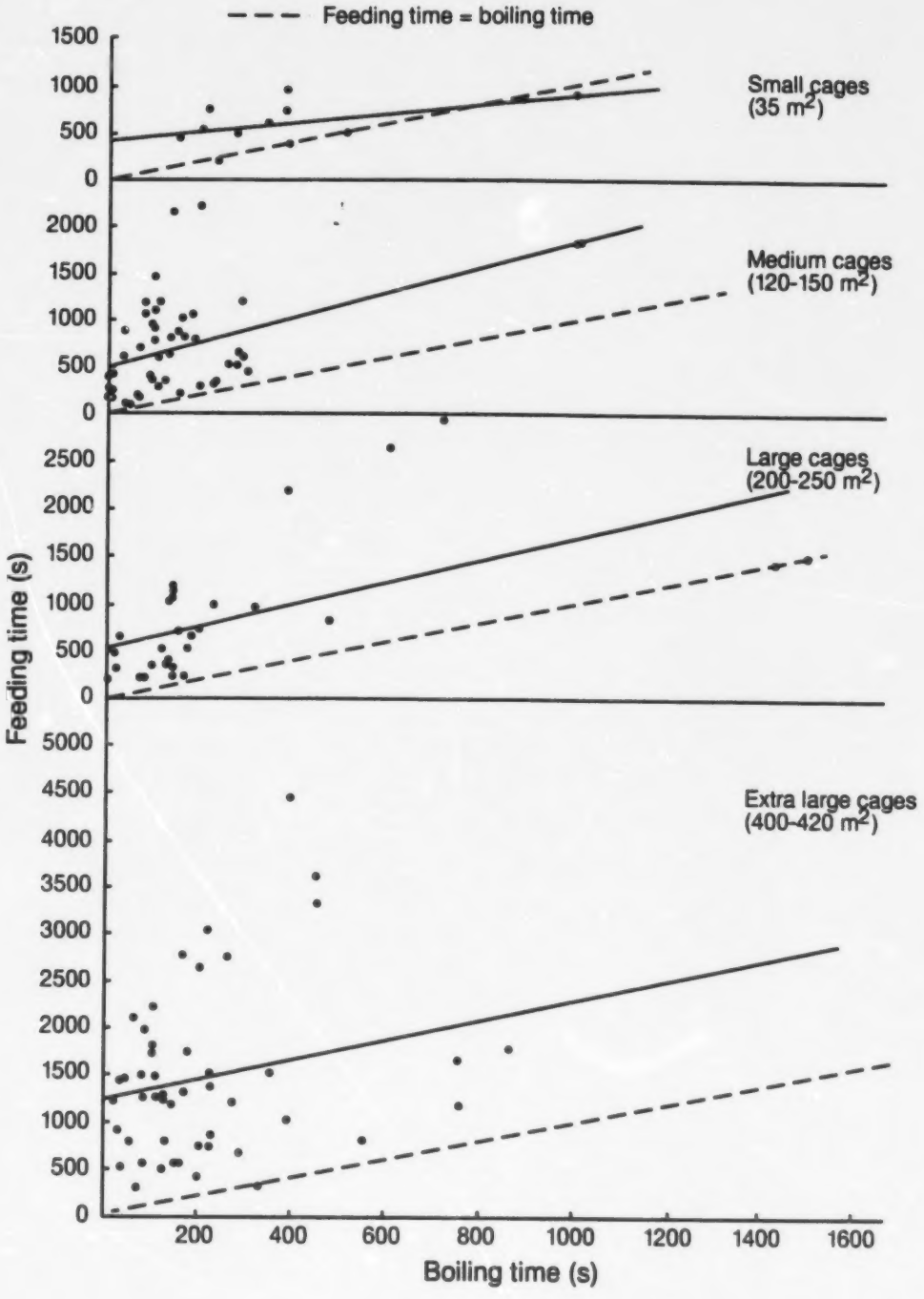


Fig. 19. The lengths of time fish were fed is plotted against the lengths of time the fish "boiled" at the surface. Solid lines are the lines of best fit. Dashed lines are lines of equality. Numbers in parentheses refer to cage surface area.

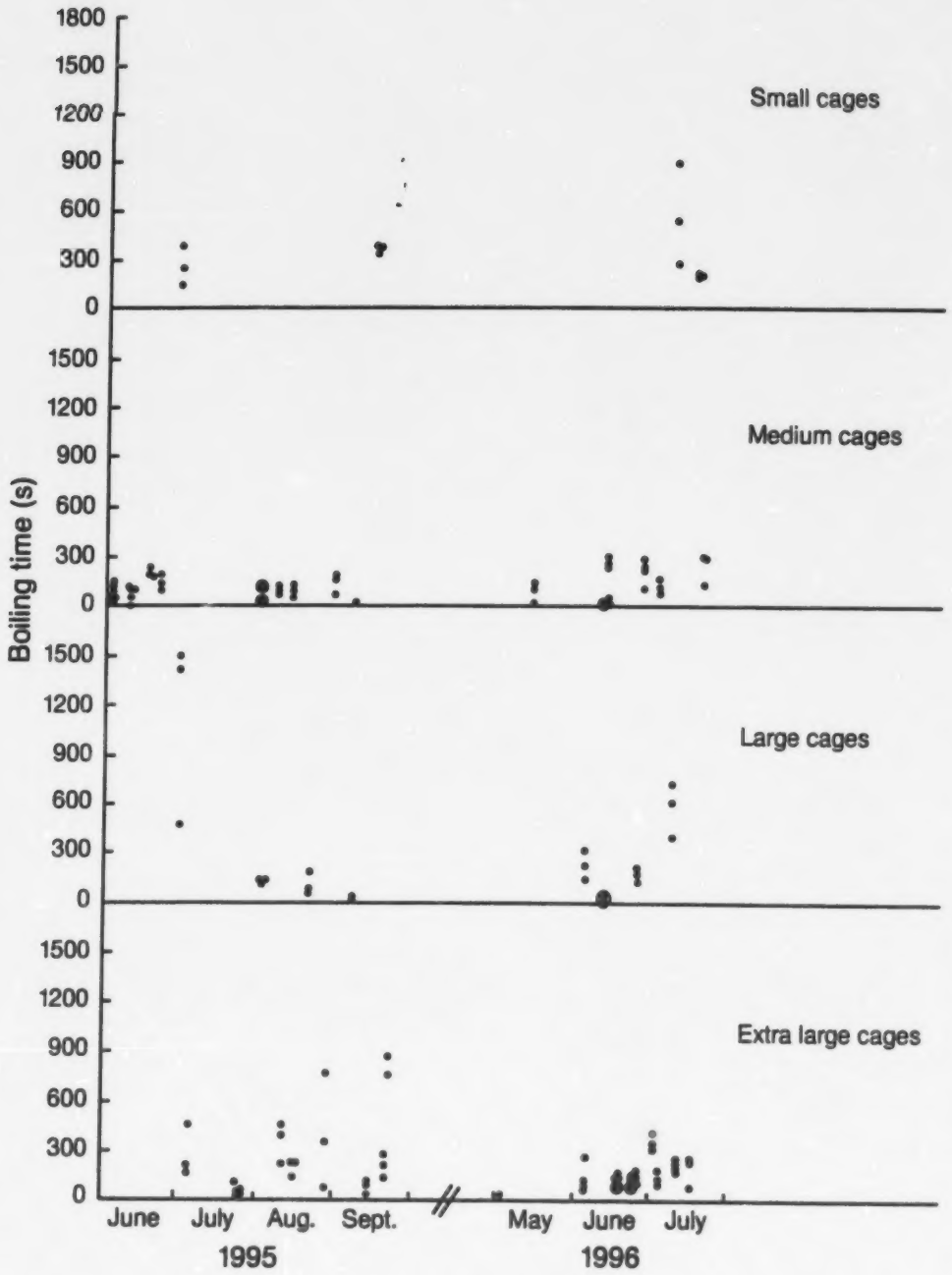


Fig. 20. Boiling times of caged salmon are shown in relation to cage size and month of year. Circled points indicate use of medicated feed. Small cages: wooden octagonal and small plastic circles; medium: square steel; large: square steel, square plastic, 50-m circles; extra large: 70-m circles.

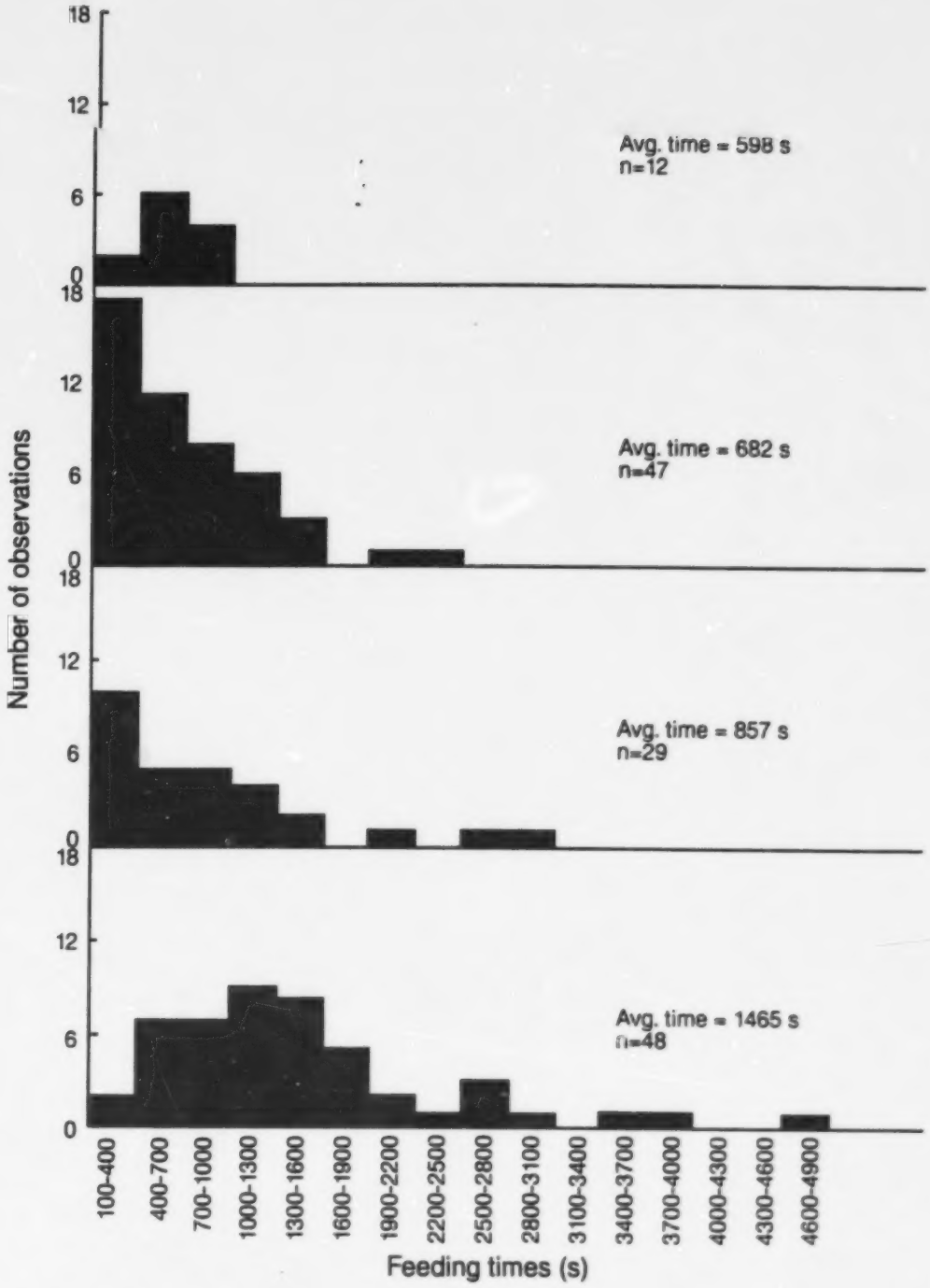


Fig. 21. Frequency histogram of lengths of time farmers fed salmon for various cage sizes. Top panel: small cages; second from top panel: medium cages; second from bottom: large cages; bottom: extra large cages.

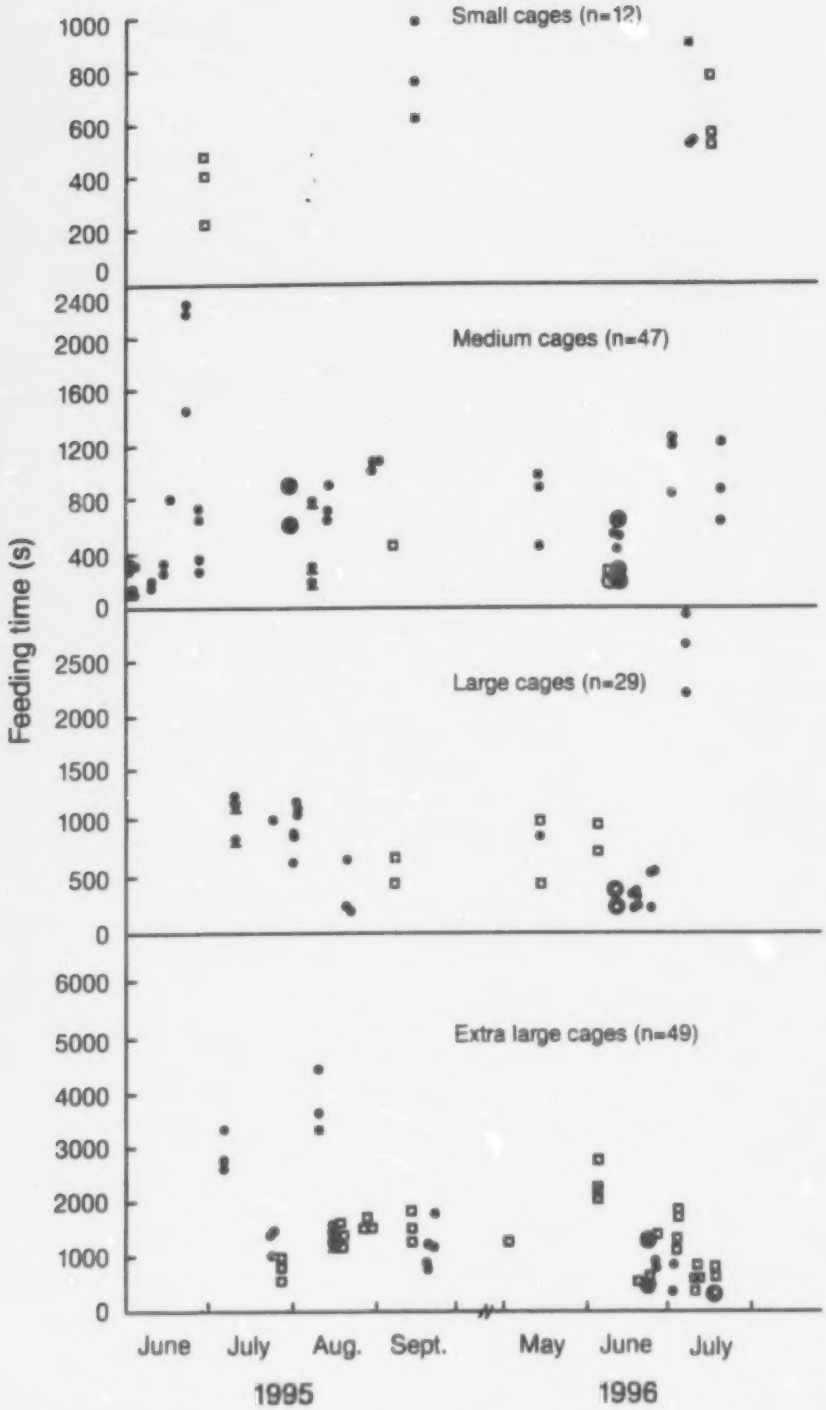


Fig. 22. Feeding times for feeding sessions in relation to cage size and month of the year. Squares: dry diet; closed circles: moist diet; encircled points: medicated diet; underlined points: Ivermectin-treated diets.

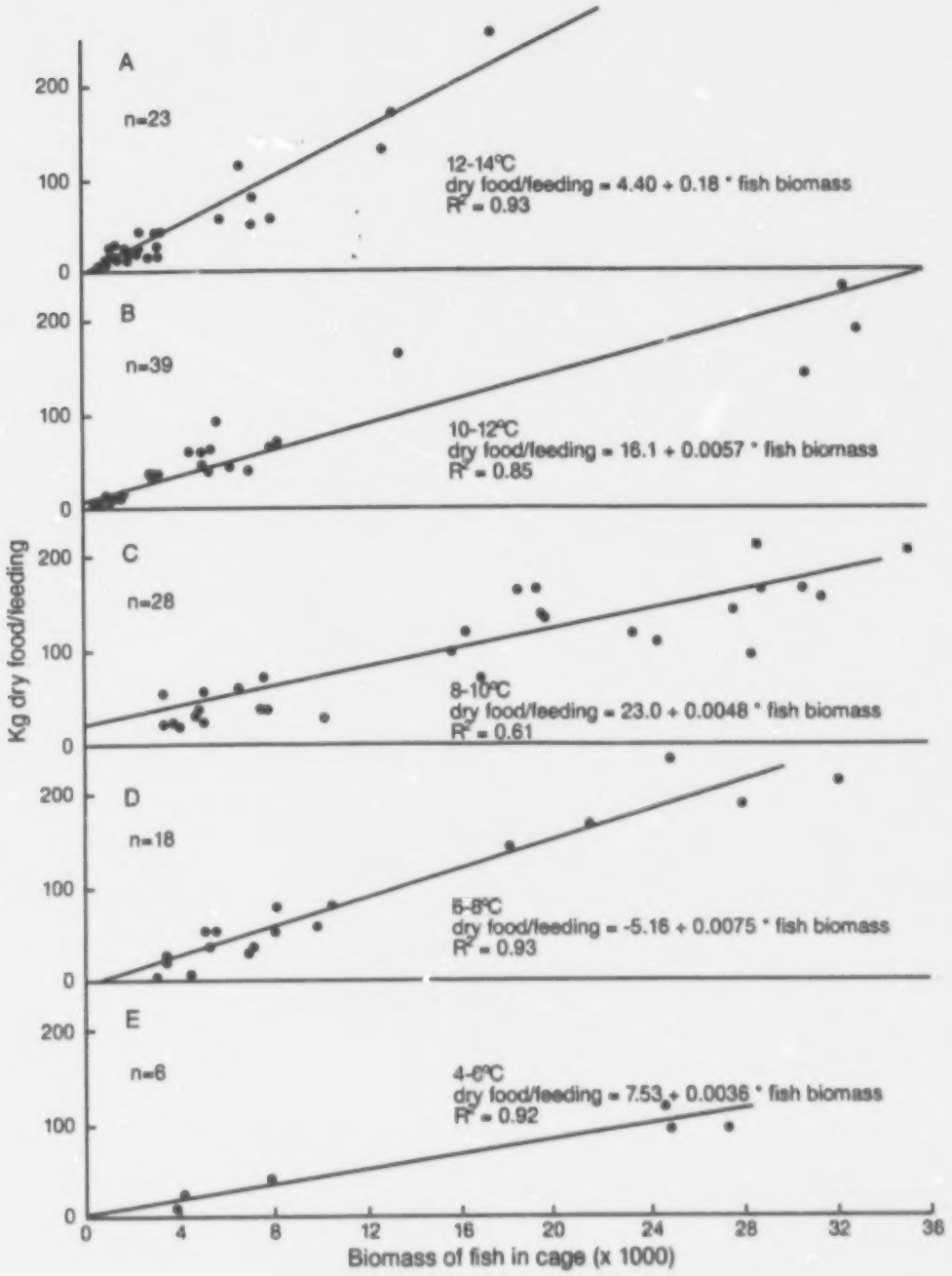


Fig. 23. Weights of feed (kg) fed to caged salmon in a single feeding in relation to the estimated biomass of fish (kg) in the cage for various temperature regimes.

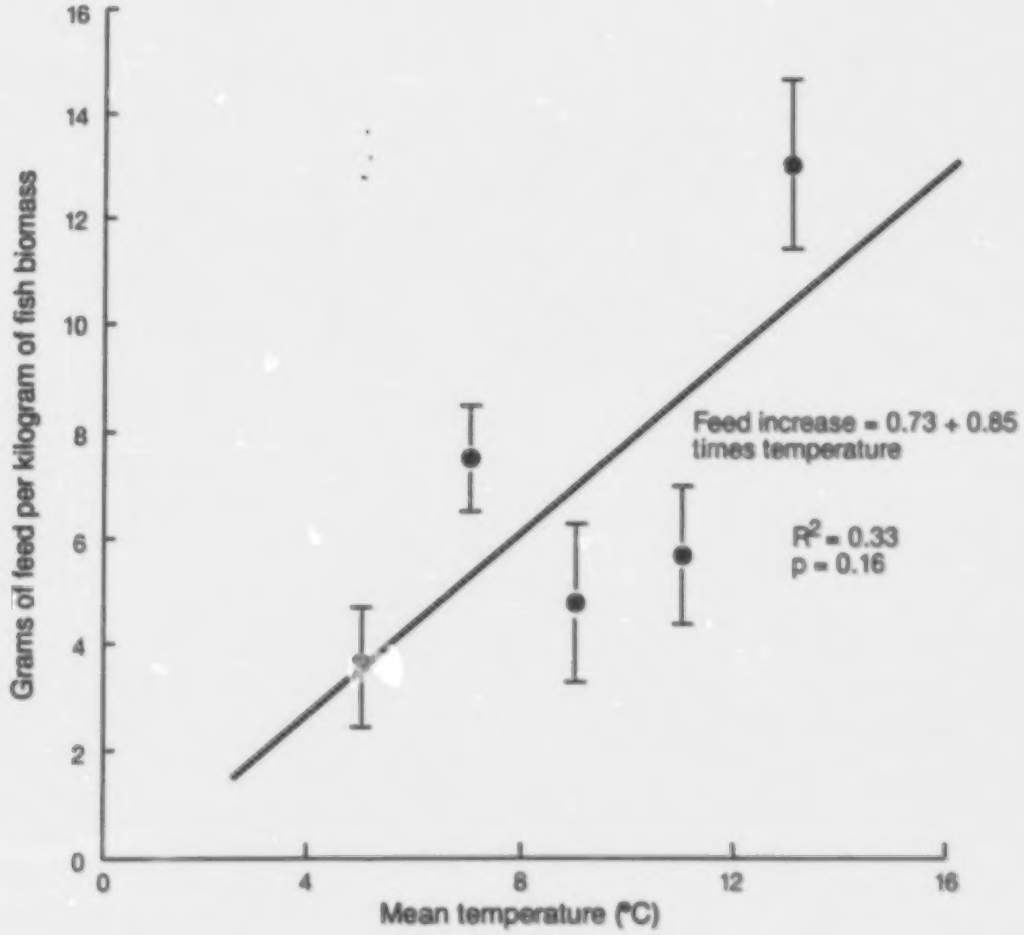


Fig. 24. Amount of feed fed in a single feeding in relation to cage biomass is plotted against cage temperature. The linear fit is not good. The relationship may not be linear.

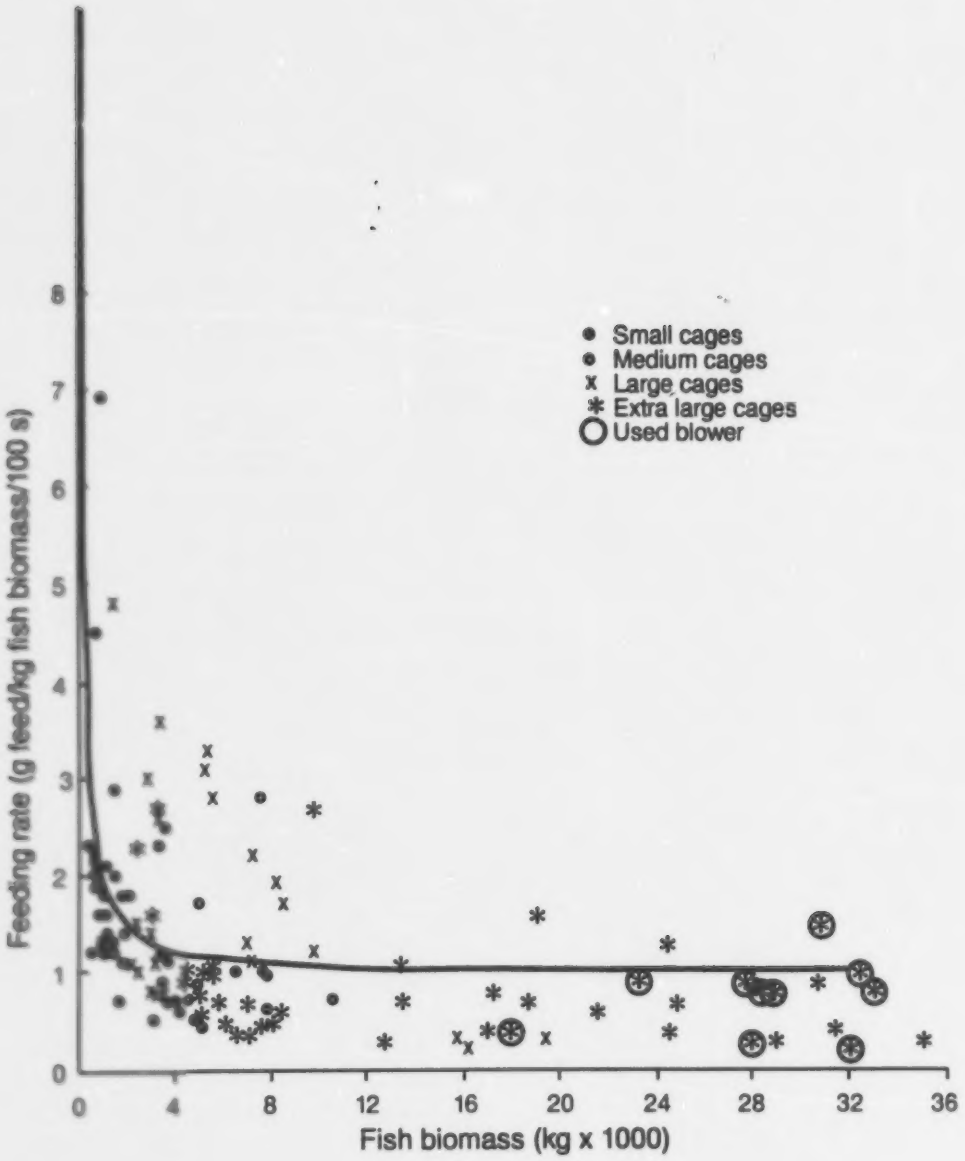


Fig. 25. Feeding rate is shown in relation to salmon biomass in the fed cage. The drawn line is the line of best fit, assuming a reciprocal relationship between feeding rate and cage biomass (feed rate = 0.96 + 1.06/fish biomass).

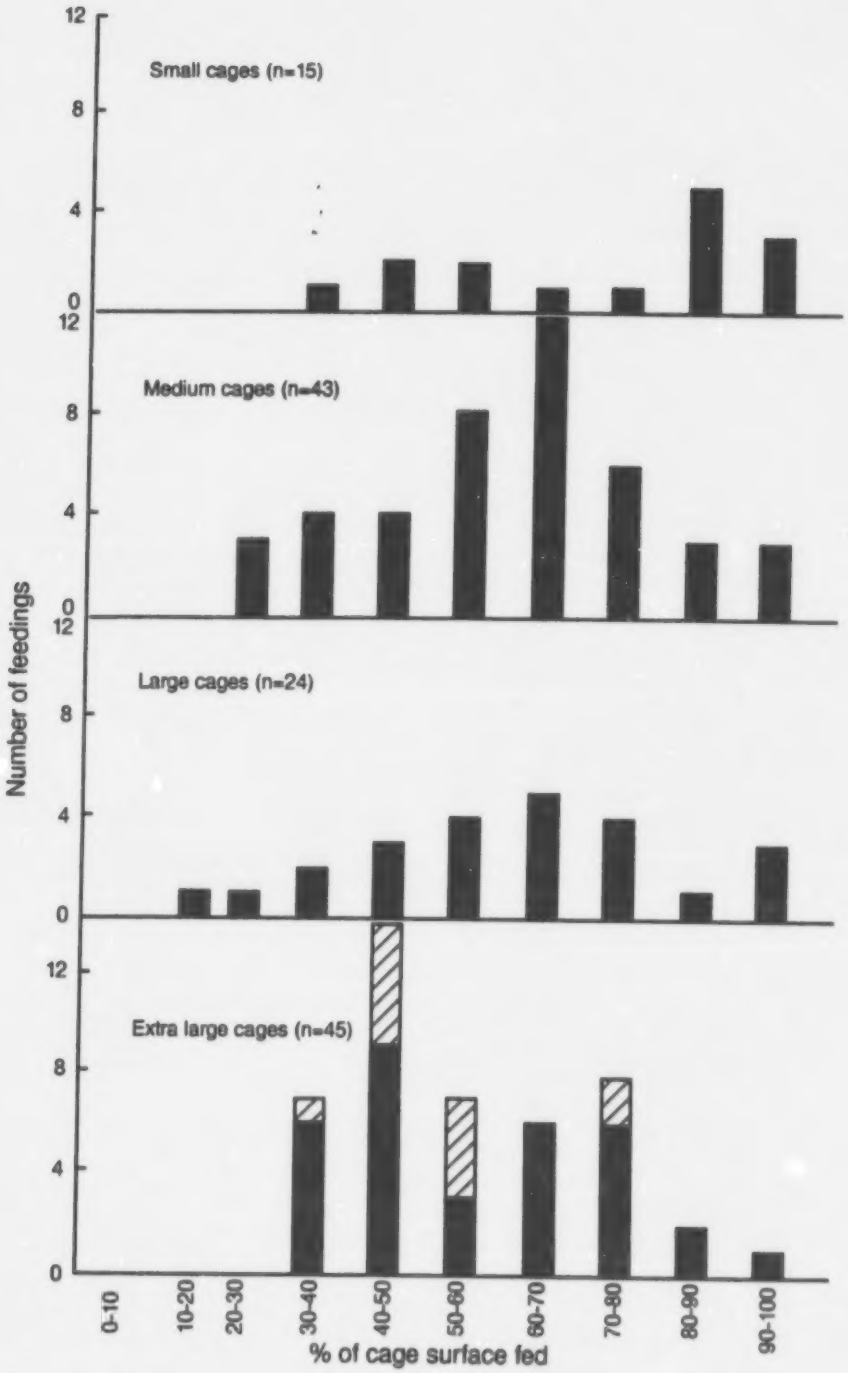


Fig. 26. Frequency distribution of percent of cage surface area to which feed was delivered in a meal. Hatched bars indicate use of feed blowers.

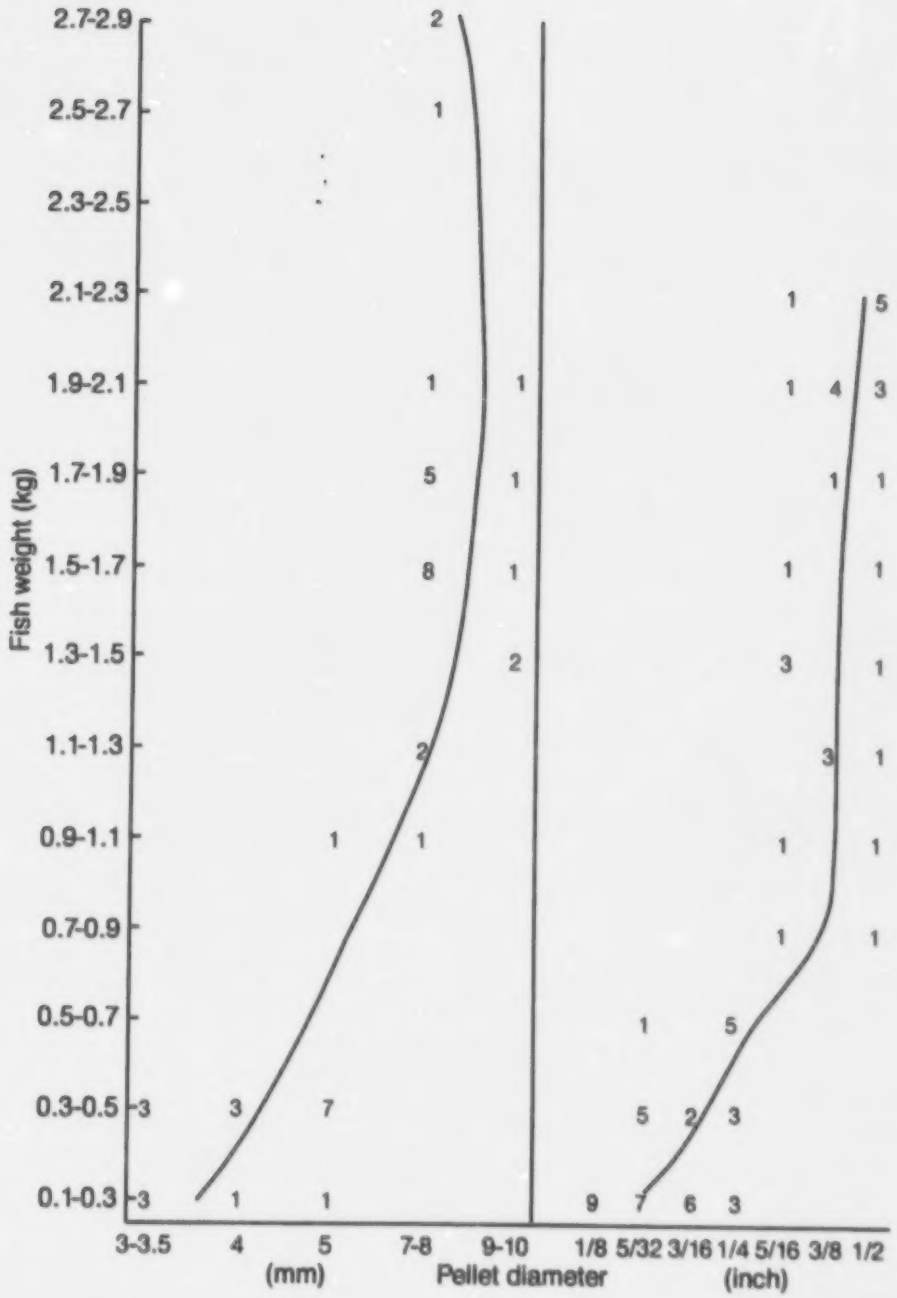


Fig. 27. Feed pellet sizes fed to caged salmon for fish of various weights. Numbers in the figure indicate the number of observations. Left panel: dry feed; right panel: moist feed.

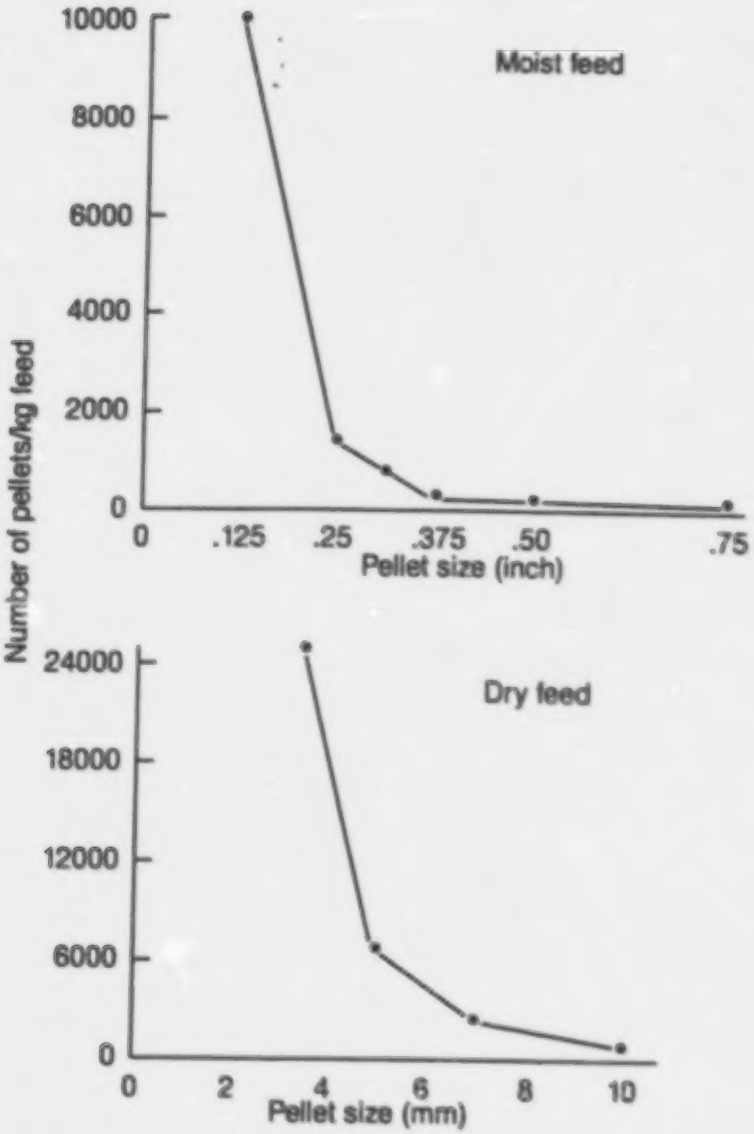


Fig. 28. The mean number of pellets per kg of feed for various pellet sizes. Upper panel: moist feed; lower panel: dry feed.

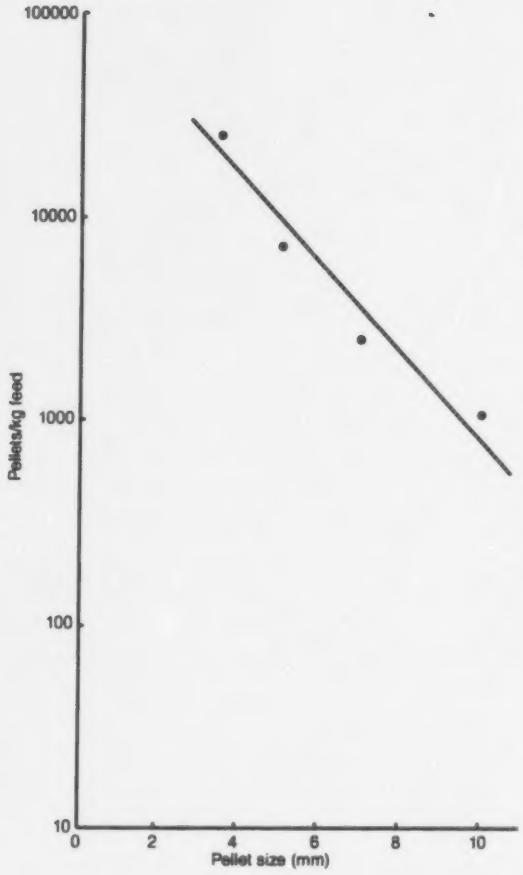


Fig. 29. Pellets per kg of dry feed vs pellet diameter on a logarithmic basis.

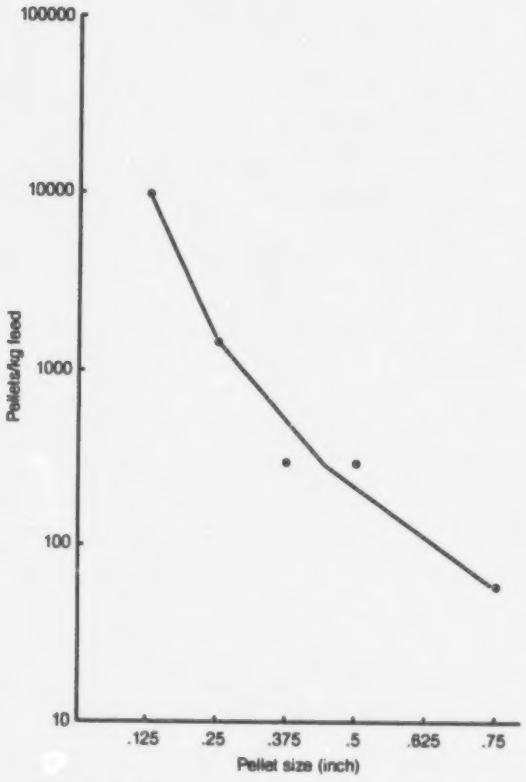


Fig. 30. Pellets per kg of moist feed vs pellet diameter on a logarithmic basis.

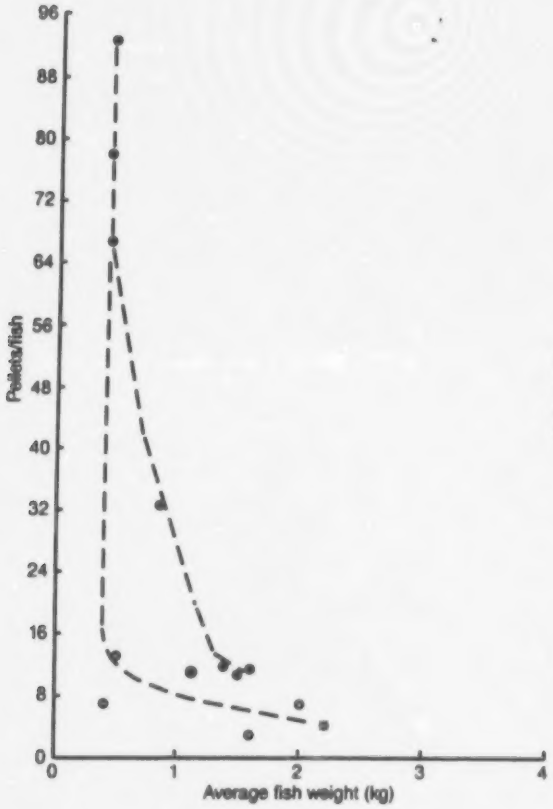


Fig. 31. Number of pellets fed per fish in a single meal in relation to mean fish weight at time of feeding, for small cages. Open circles: moist feed; closed circles: dry feed.

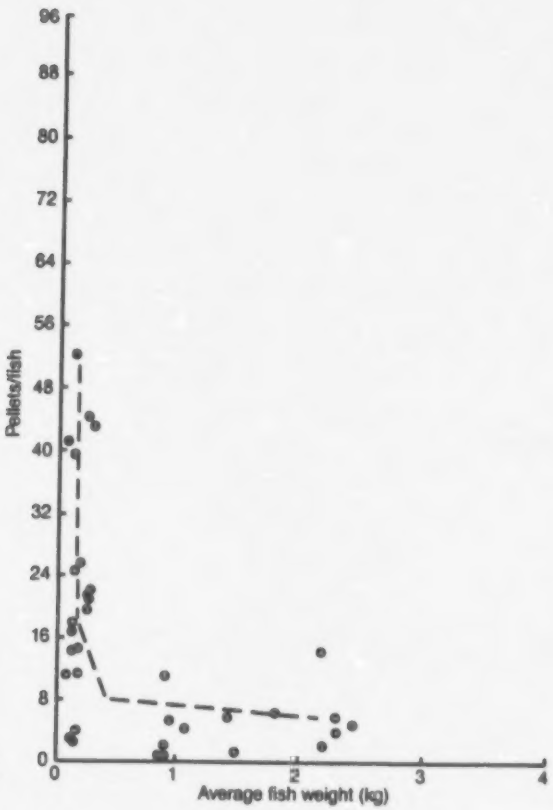


Fig. 32. Number of pellets fed per fish in a single meal in relation to mean fish weight at time of feeding for medium cages. Open circles: moist feed; closed circles: dry feed.

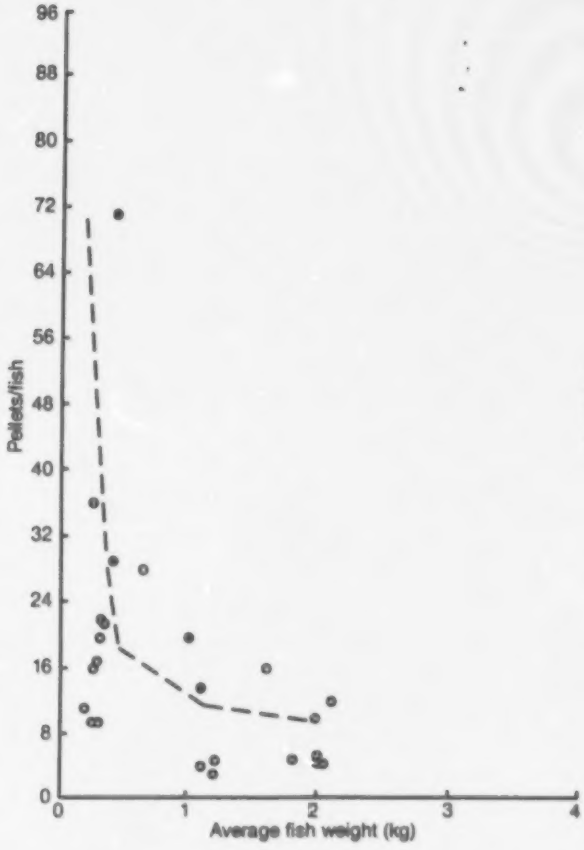


Fig. 33. Number of pellets fed per fish in a single meal in relation to mean fish weight at time of feeding for large cages. Open circles: moist feed; closed circles: dry feed.

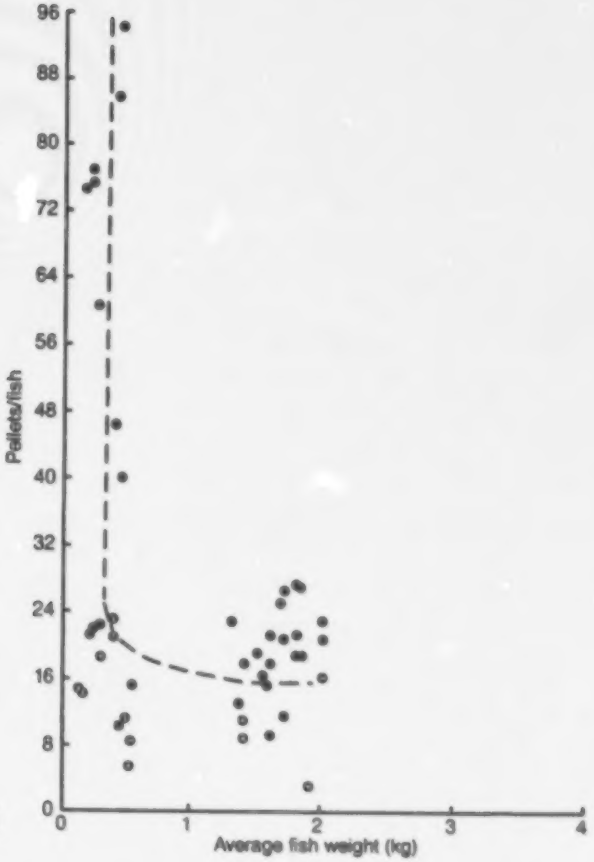


Fig. 34. Number of pellets fed per fish in a single meal in relation to mean fish weight at time of feeding for extra large cages. Open circles: moist feed; closed circles: dry feed.

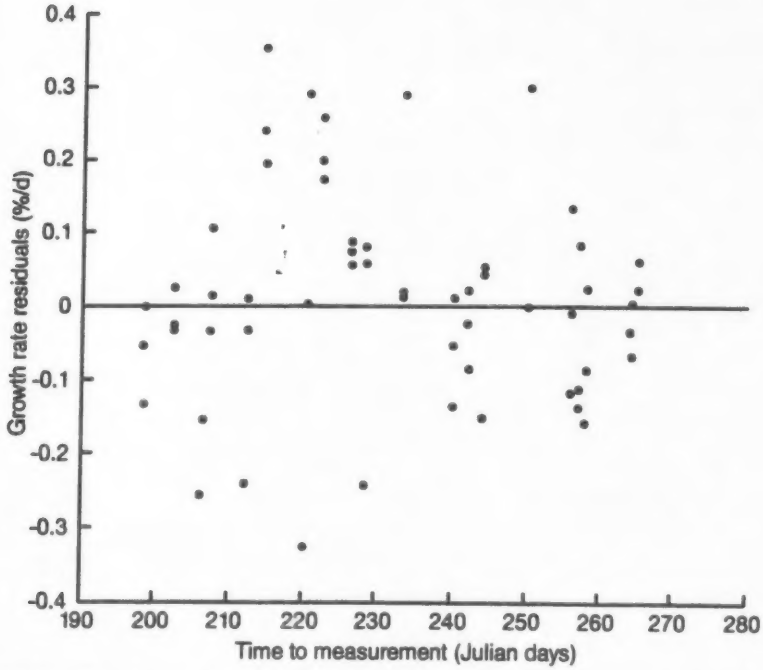


Fig. 35. Specific growth rate residuals for the first summer's measurements, using model 3 (see text). Residuals show no trend with time of measurement. Growth rate residuals are the differences between measured and predicted estimates of growth rate, as derived from the regression $\log G = -0.6908 + 0.001975t_f + 0.003441t_i - 0.001567S$, where logG is the logarithm of estimated specific growth rate, t_f is the time when fish size was measured, t_i is the time of smolt entry, and S is the initial smolt size.

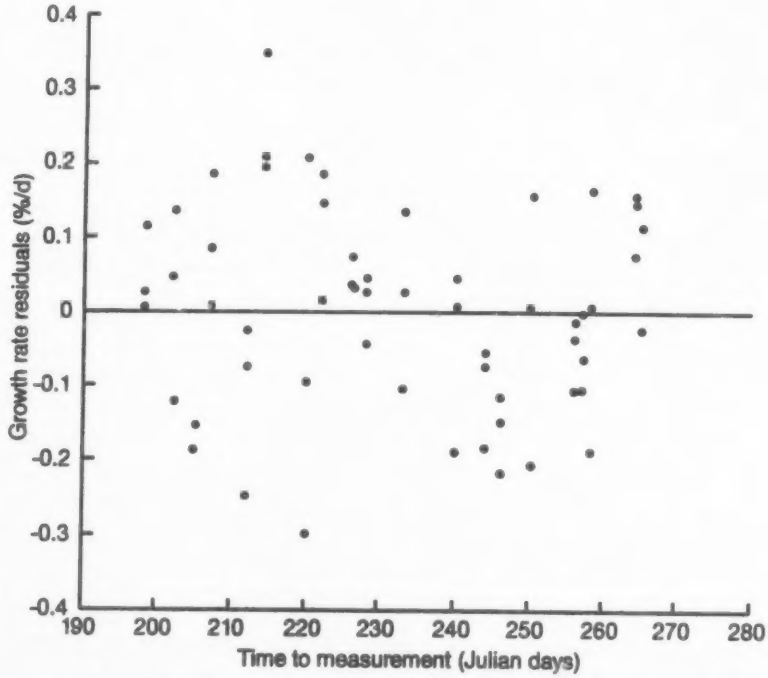


Fig. 36. As with Fig. 35, but estimated specific growth rates were calculated with model 1: $G = 9.2033 + 0.007533S + 0.07431t_f + 0.0002743S^2 - 0.0001365t_f^2 - 0.00007787t_f S + 0.01033t_i$. Again, no bias due to time of measurement is indicated.

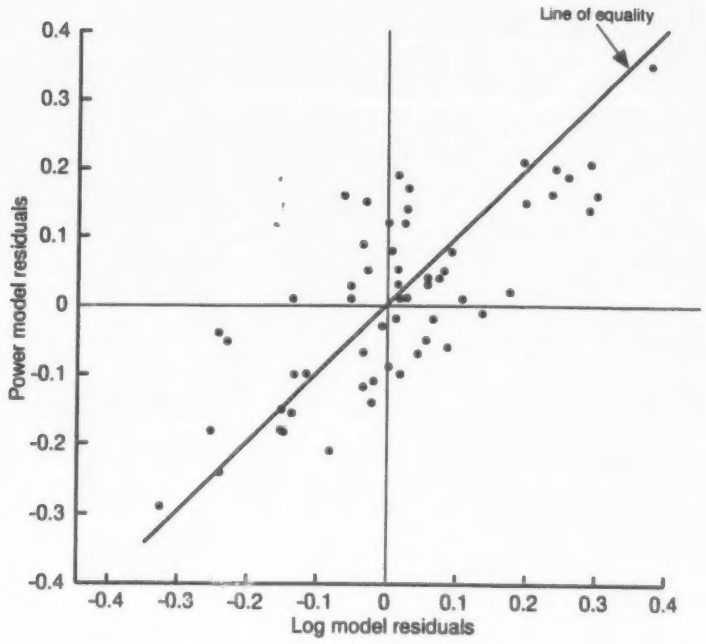


Fig. 37. "Power" model (Fig. 36) specific growth rate residuals are plotted against the "Semilogarithmic" model residuals, showing general equivalence of residuals.

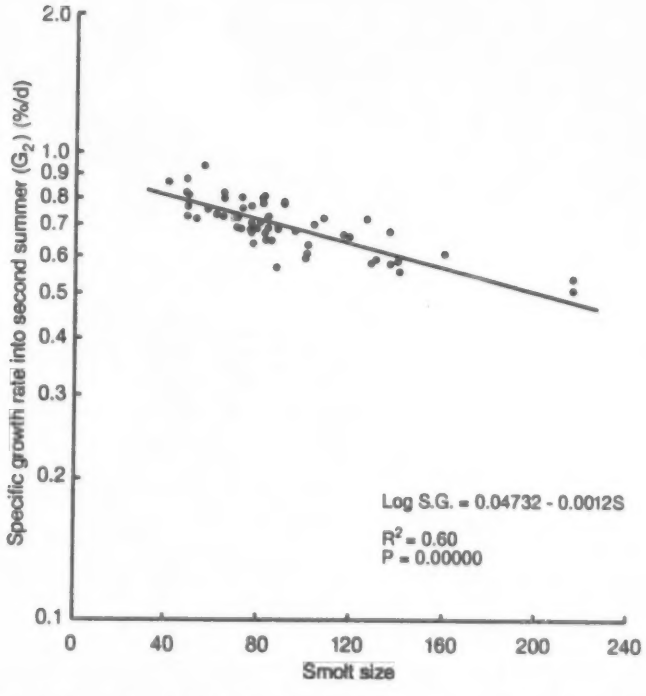


Fig. 38. Semilogarithmic plot of specific growth rates from smolt entry until early in the second summer against initial smolt size (g). Line is regression of least squares best fit (equation on figure).

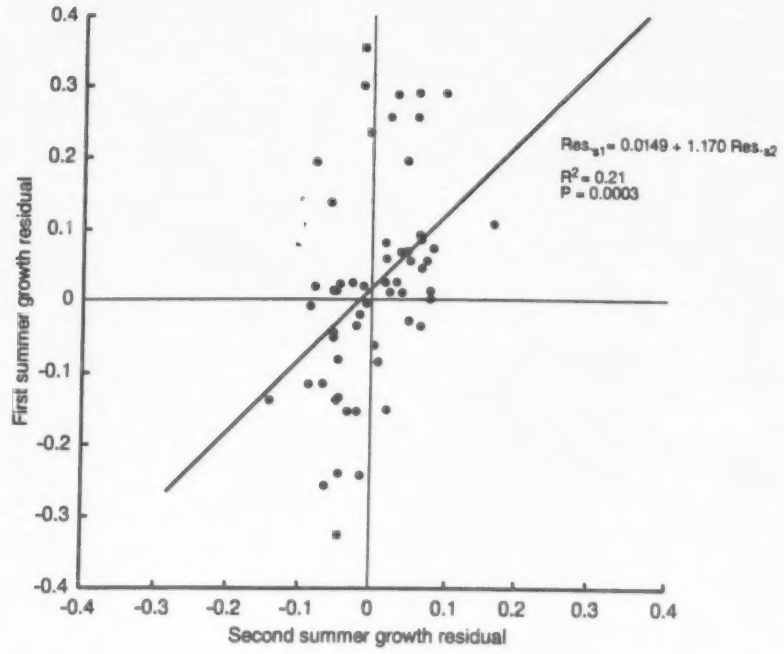


Fig. 39. Specific growth rate residuals for the first summer (using Model 2) vs specific growth rate residuals for the second summer (from regression shown in Fig. 38). Generally, cages of fish that grew better than average in the first summer (positive residuals) also had above average growth into the second summer.

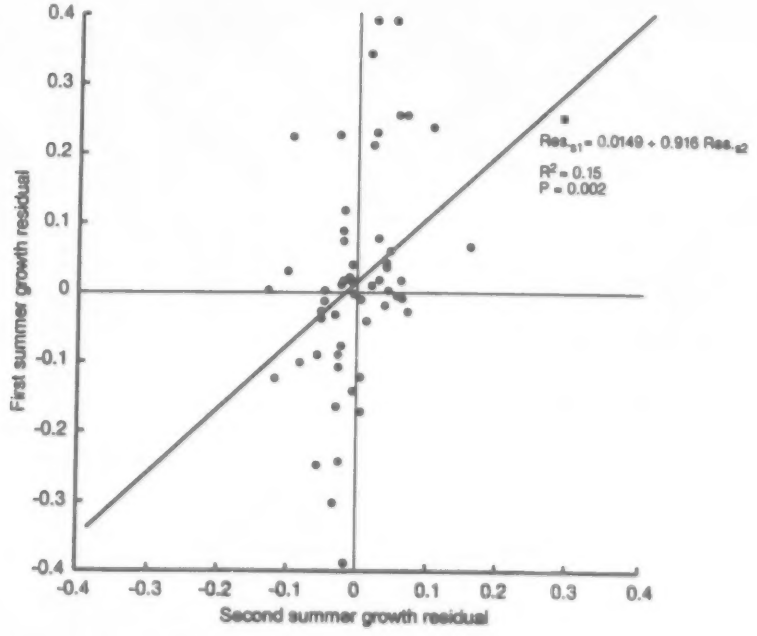


Fig. 40. Specific growth rate residuals for the first summer (using model 3) vs specific growth rate residuals for the second summer.

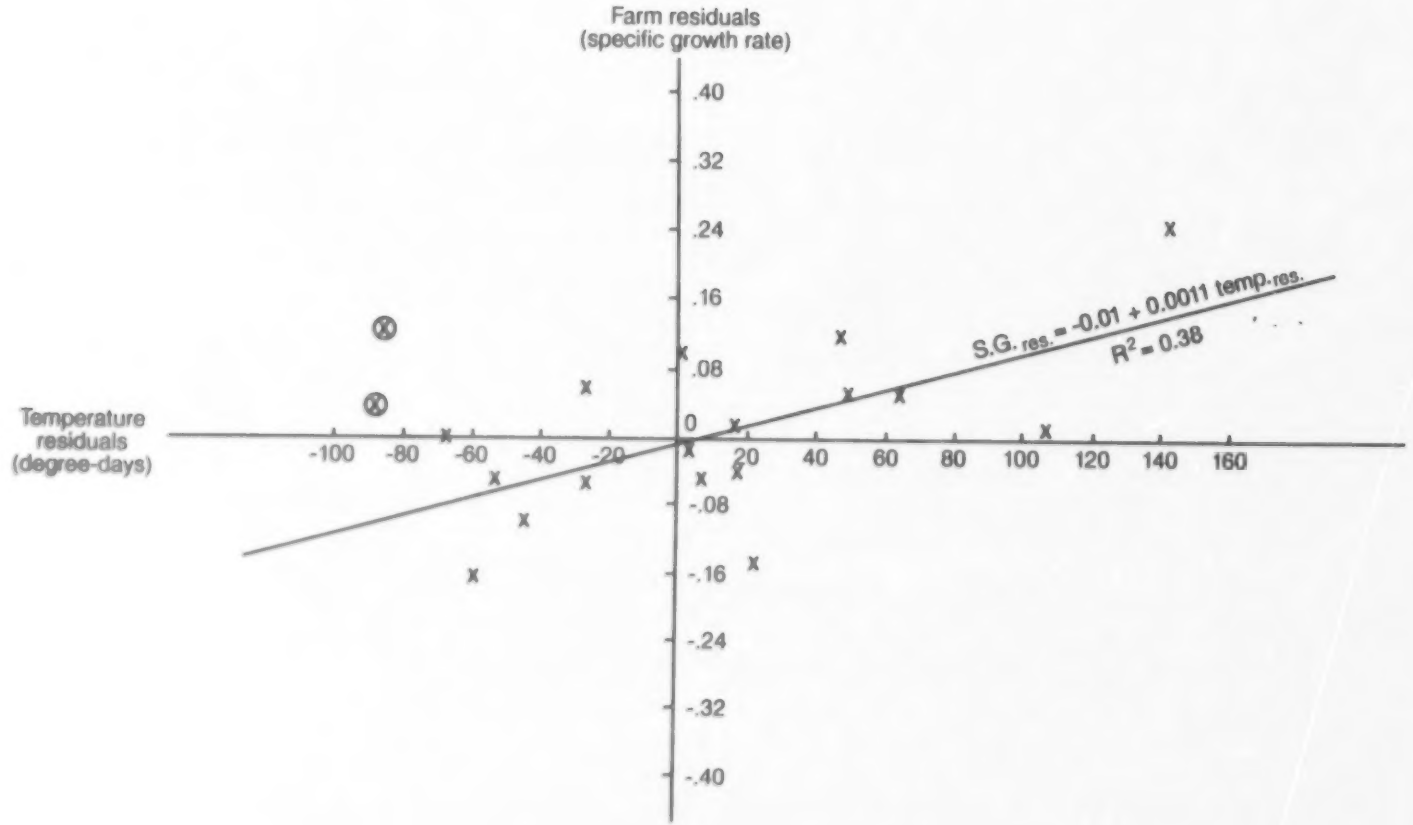


Fig. 41. Specific growth rate residuals for monitored farms (3 cages averaged) the first summer (model 3) plotted against the thermal degree-day residuals for the same farms. The thermal degree-day residuals are the differences between the average number of accumulated degree-days for all farms from May 15-September 15, and the accumulated degree-days for individual farms. Circled farms (Grand Manan) not included in the calculation of the regression.

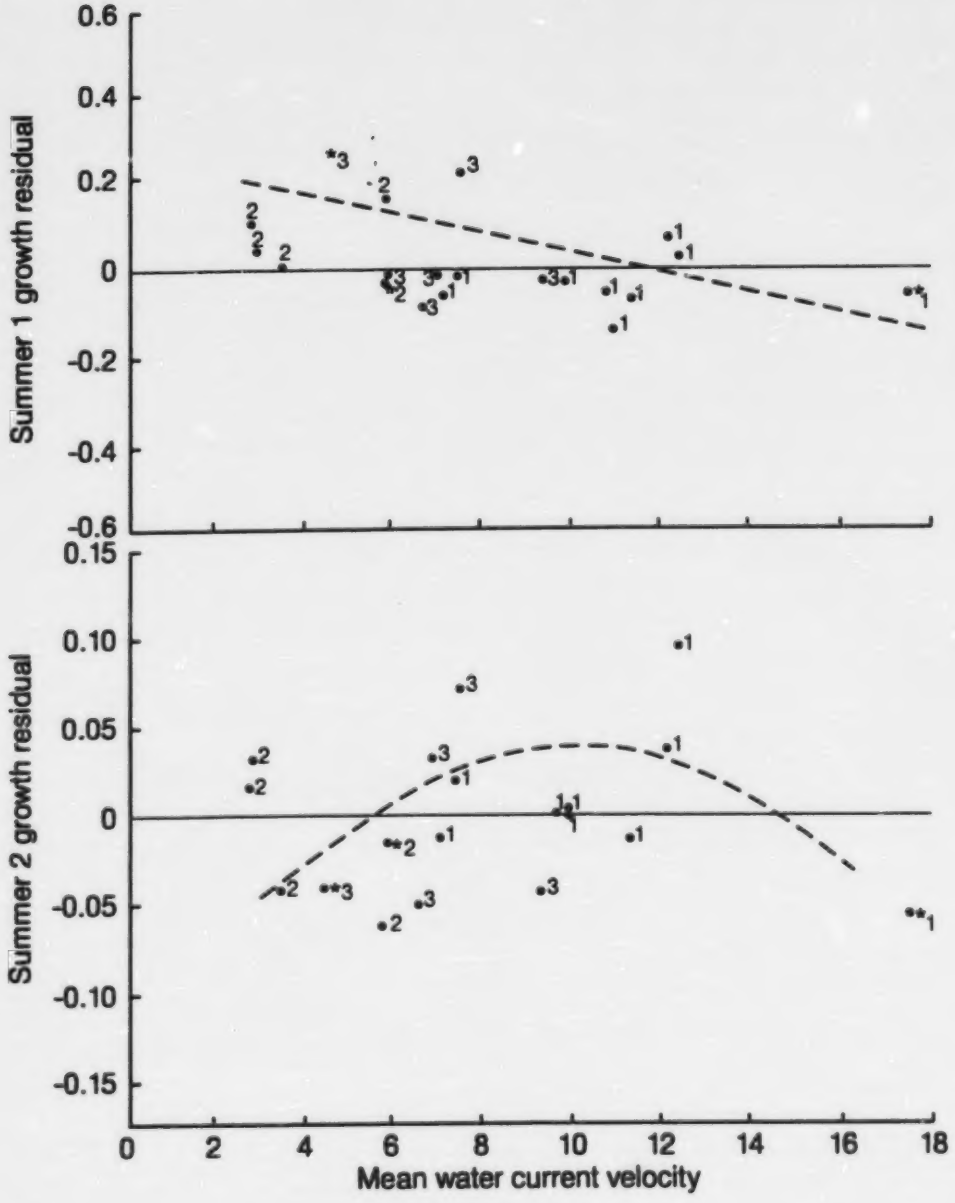


Fig. 42. First summer's specific growth rate residuals (model 3) (upper panel) and second summer's specific growth rate residuals (lower panel) for monitored farms (3 cages averaged) are shown in relation to mean water current velocity for the farms. Numbers on data points refer to the clusters of Fig. 5. Asterisks indicate outliers from the cluster analysis.

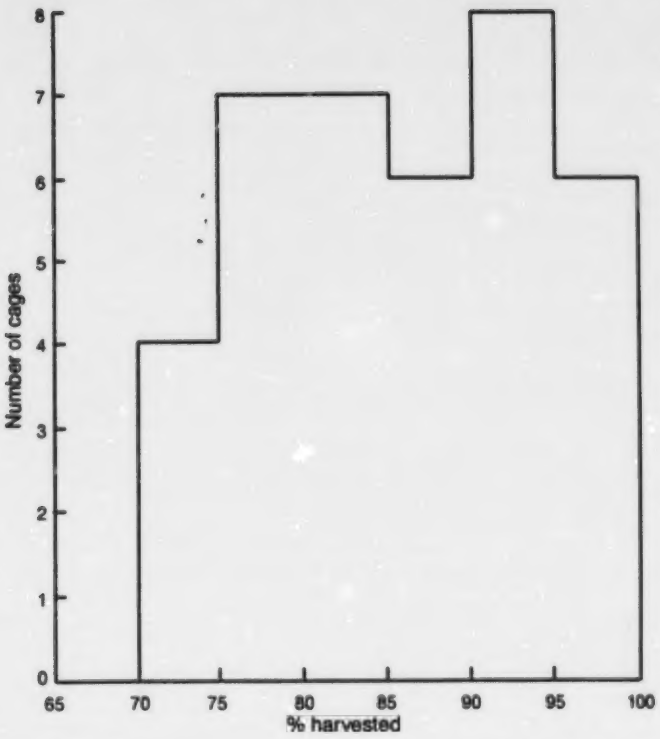


Fig. 43. Frequency histogram of percentages of numbers of smolts placed in monitored cages that were harvested. The totals for each bar of the histogram are for the spans of percentages harvested (e.g. 6 cages for 95-100%).

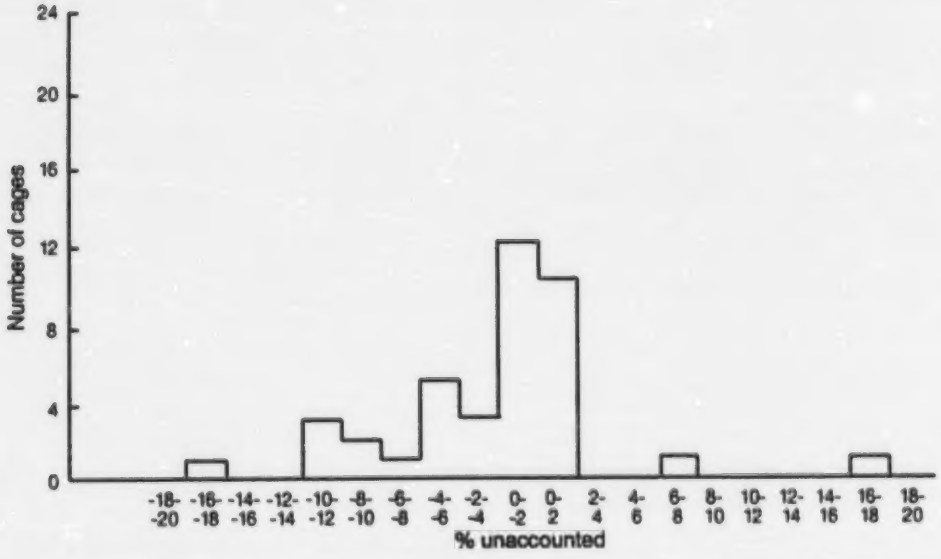


Fig. 44. A balance diagram of the number of smolts that were unaccounted for when the recorded mortalities plus harvest numbers were subtracted from the number of smolts initially placed in the cages. A negative balance means that more smolts were initially installed than could be accounted for. A positive balance means that the summed mortalities and harvested fish exceeded the recorded smolt entry for a cage.

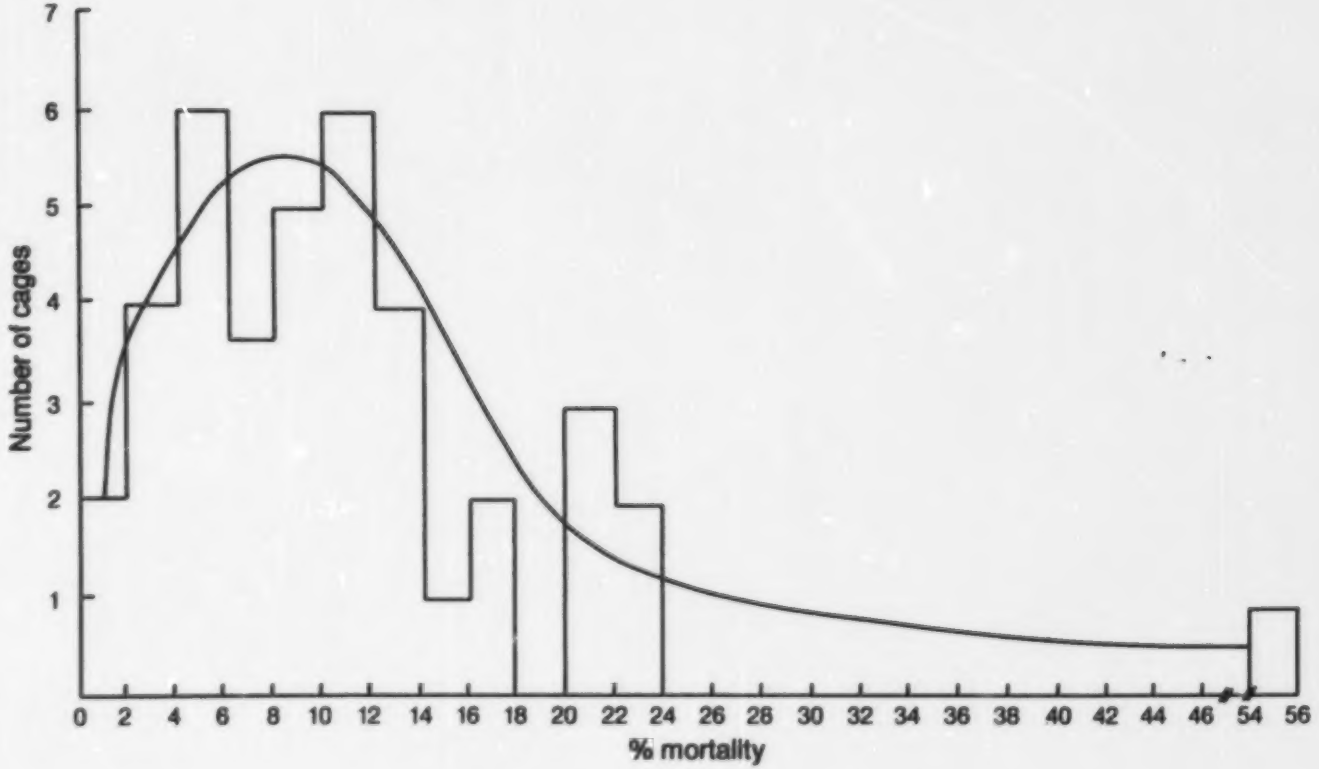


Fig. 45. Frequency of the percent mortalities for the monitored cages. The smoothing line fitted by eye.

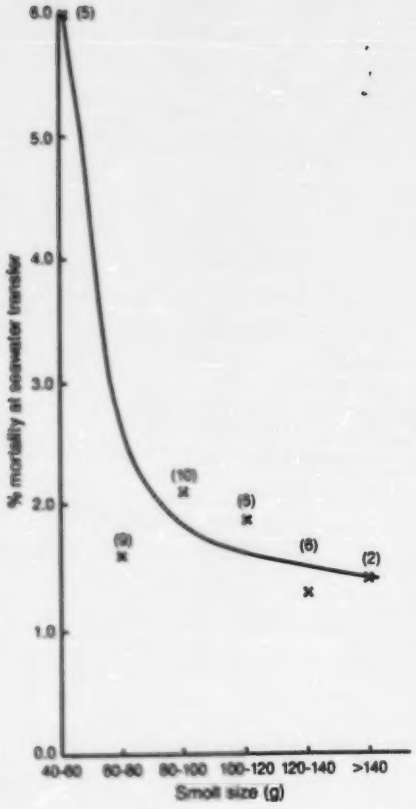


Fig. 46. Initial mean smolt mortalities are shown for various smolt size-classes. Numbers in parentheses indicate number of cages for each data point.

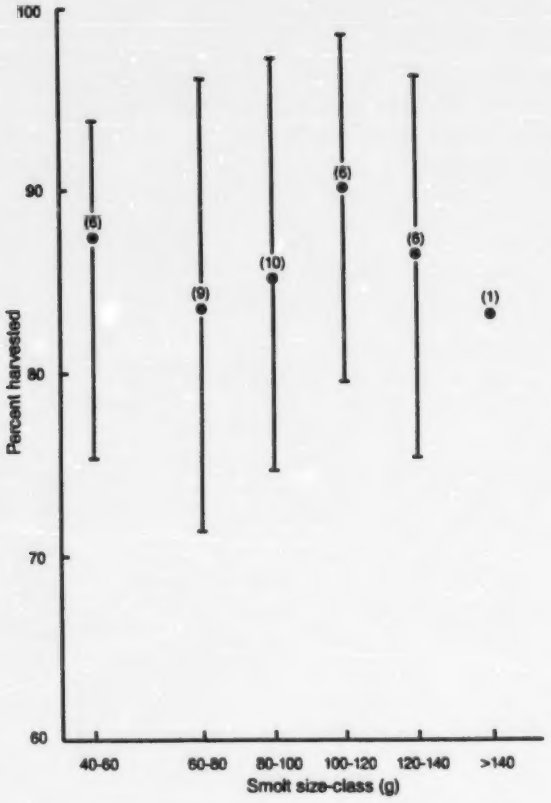


Fig. 47. Percentages of initial smolt numbers that were harvested for each smolt size-class. Numbers in parentheses indicate numbers of cages. Ranges indicated by vertical bars.

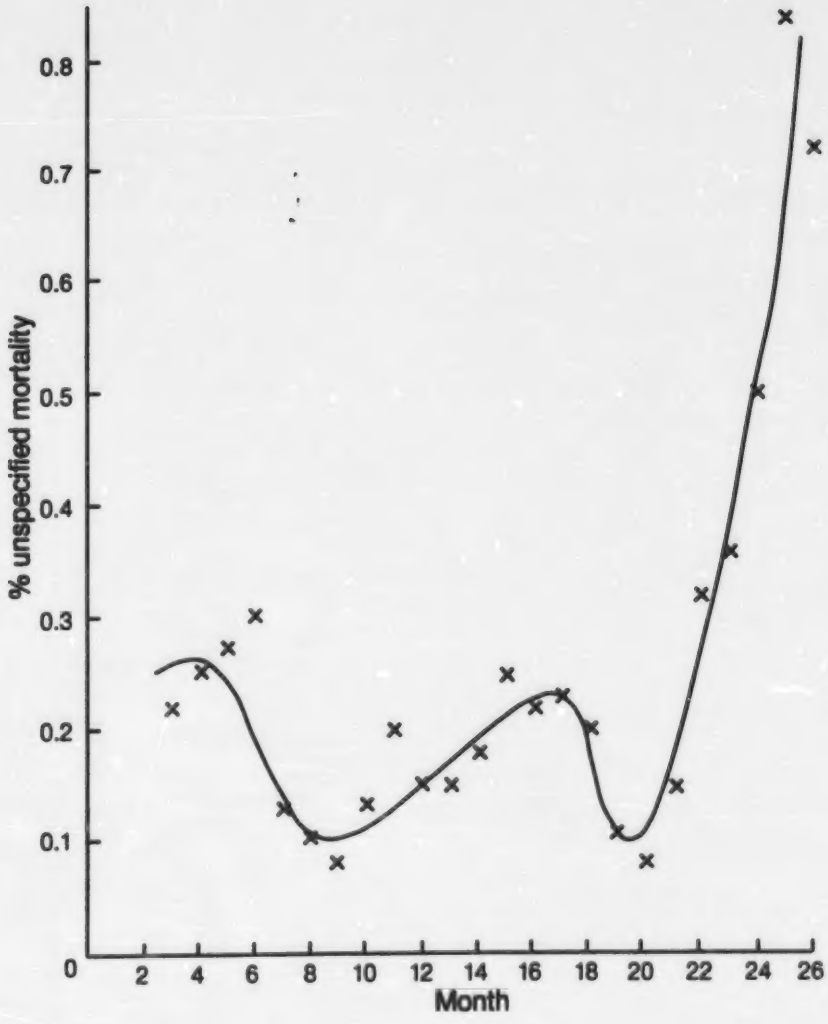


Fig. 48. Percentages of "unspecified" mortalities (no recorded cause) in relation to number of months from mean smolt entry date. Data points are means of 35 cages.

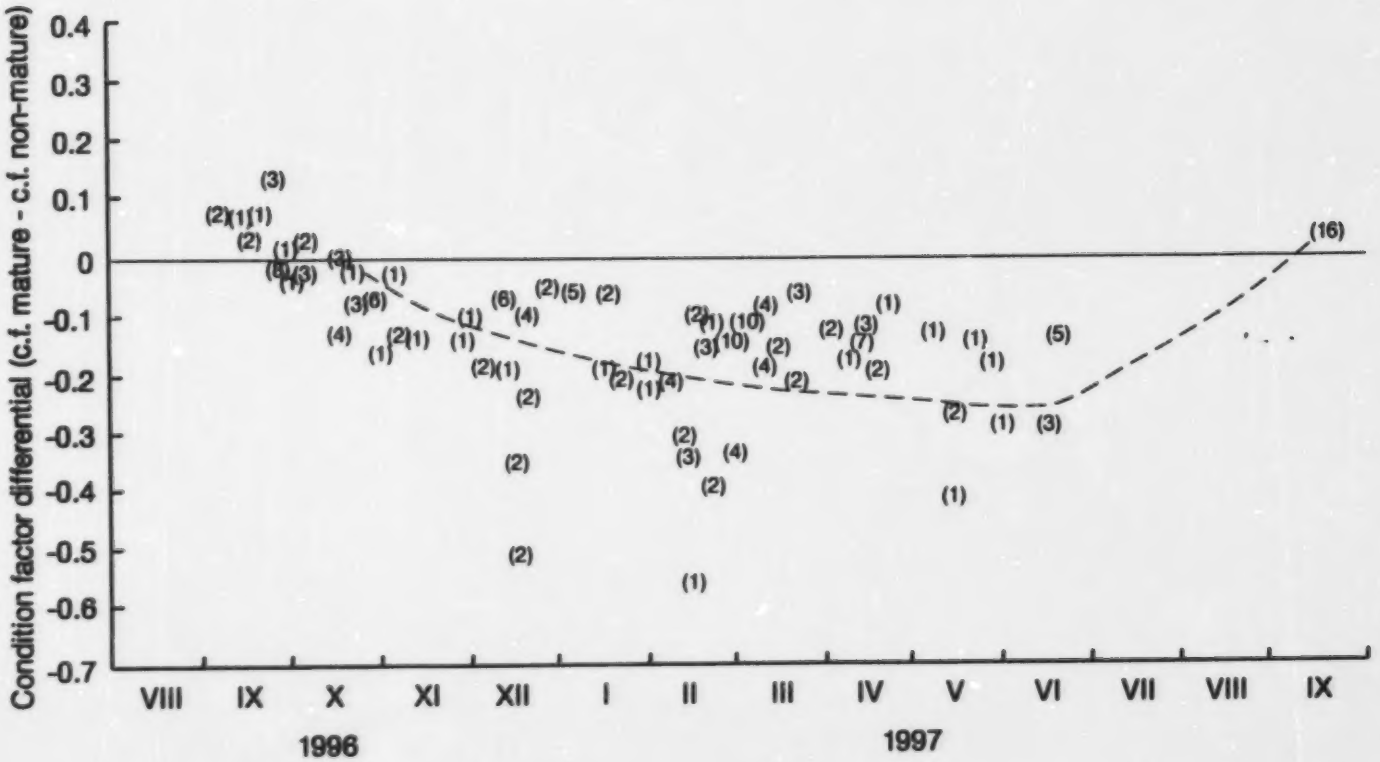


Fig. 49. The differences in condition factor between mature males and immature males from the same harvest batch are shown for various harvest dates (cf mature-cf immature). Numbers for data points indicate the numbers of mature males in each batch.

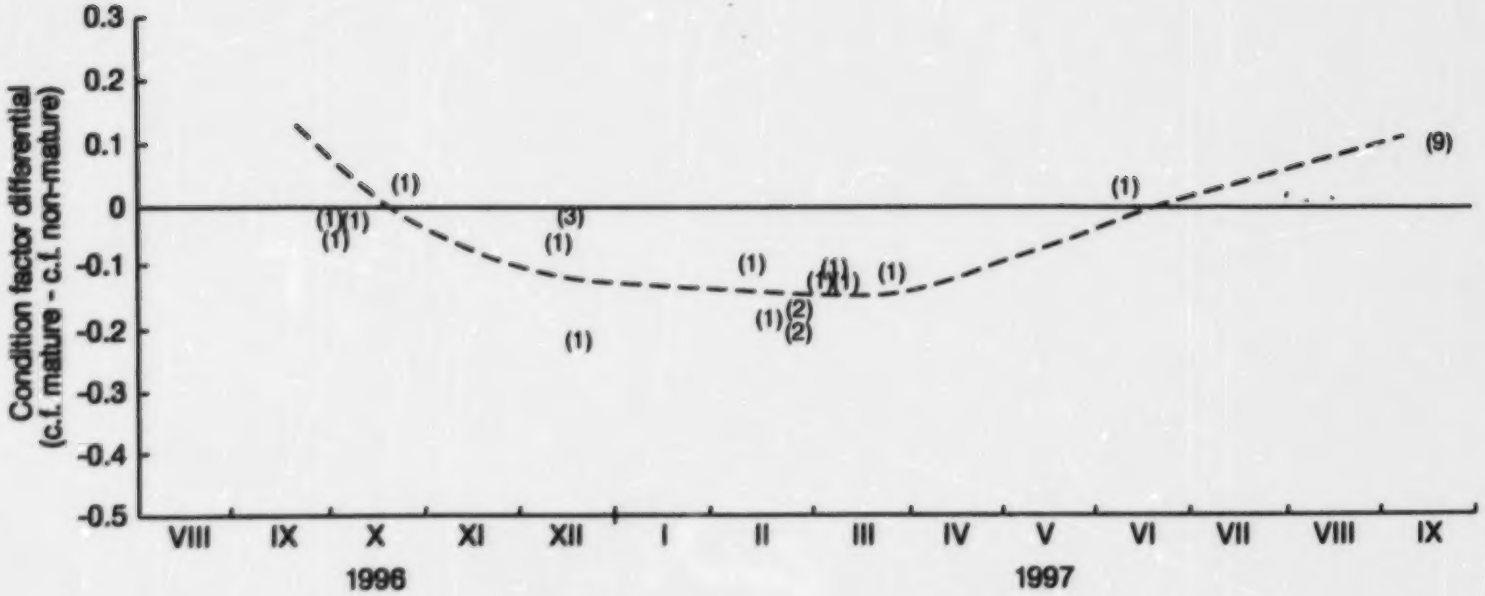


Fig. 50. The differences in condition factor between mature females and immature females from the same harvest batch are shown for various harvest dates (cf mature-cf immature). Numbers for data points indicate the numbers of mature females in each batch.

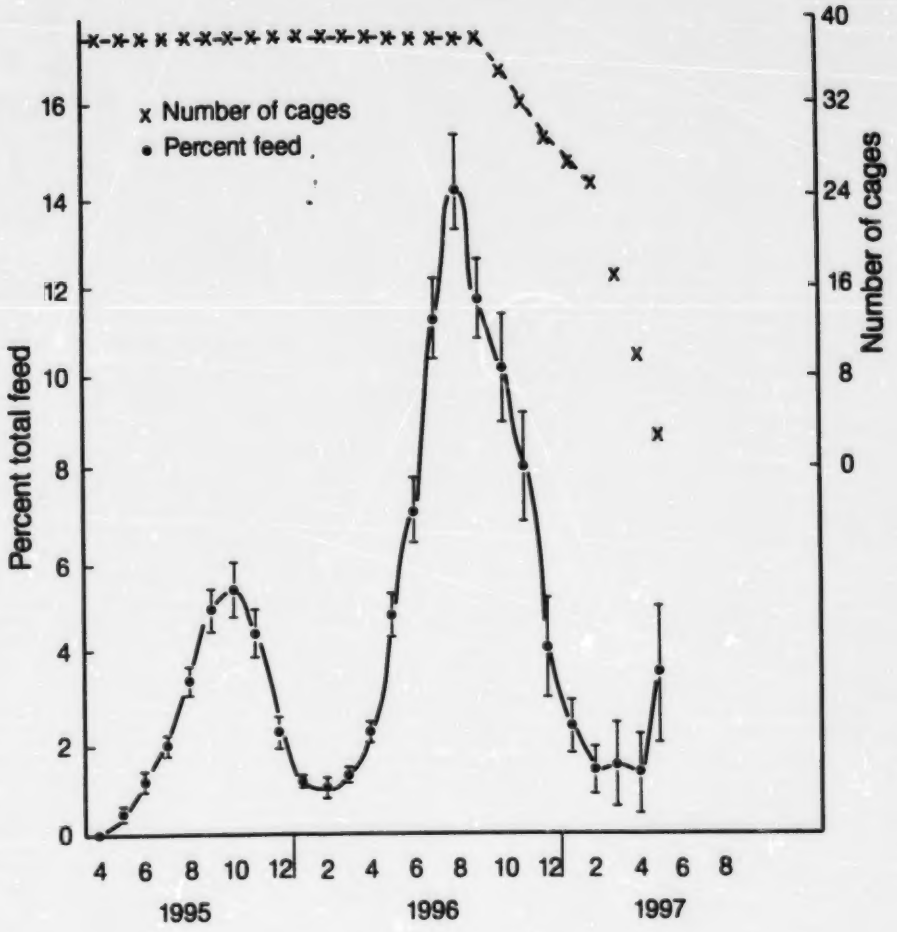


Fig. 51. Monthly feed totals (moisture subtracted) expressed as a percentage of the total feed weight delivered to the cages. The number of cages that were averaged is indicated by the dashed line. Vertical bars indicate ±95% confidence limits.

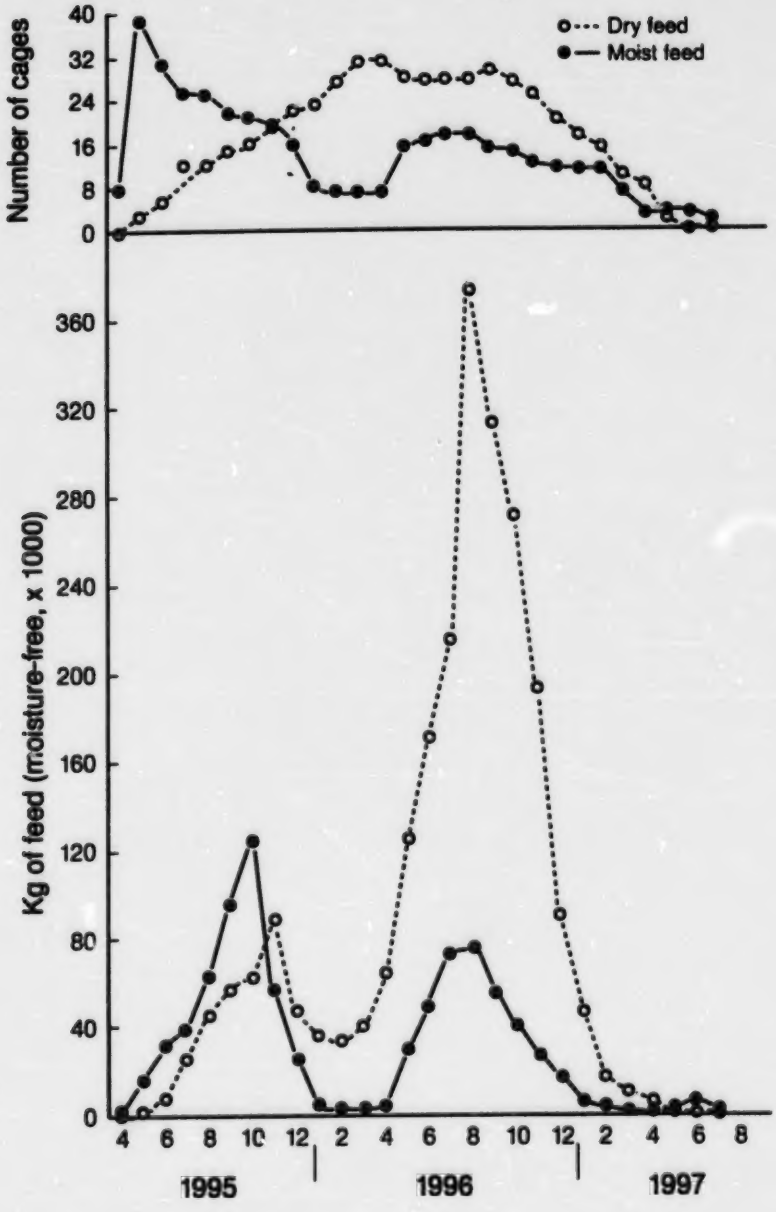


Fig. 52. Monthly amounts of moist (closed circles) and dry (open circles) feed (moisture subtracted) fed to salmon in the monitored cages (lower panel). Number of cages receiving moist and dry feed shown in upper panel. Number of cages decreases in 1997 as fish are harvested.

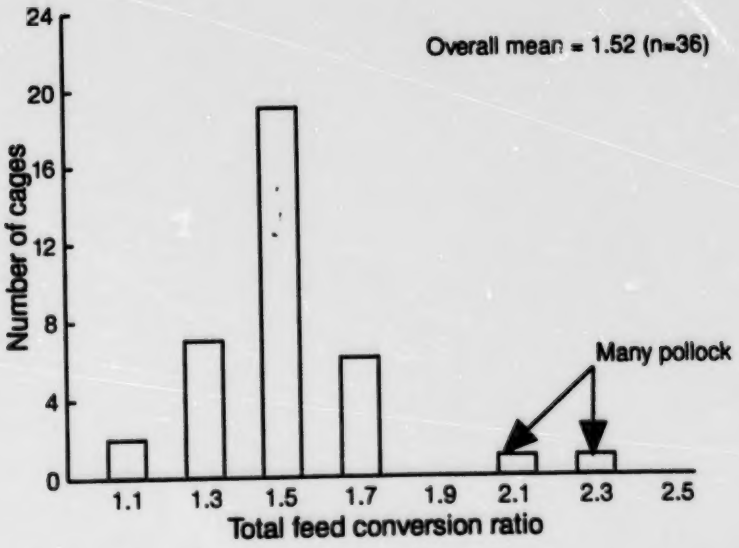


Fig. 53. Frequency distribution of feed conversion ratios (total feed (moisture subtracted) delivered to a cage/ total biomass of fish harvested).

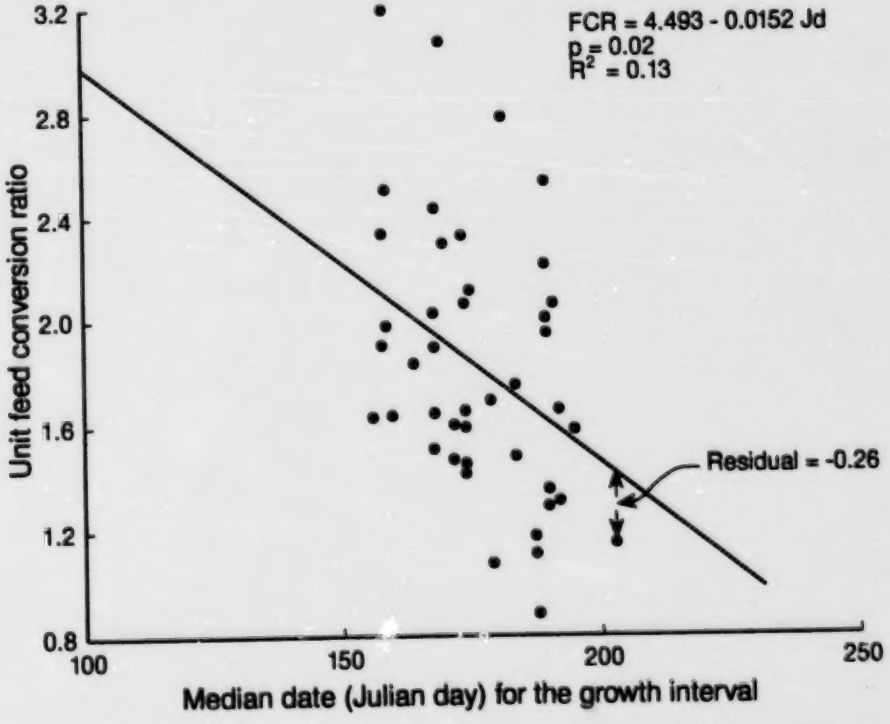


Fig. 54. Change in unit feed conversion ratio (total feed fed per fish from smolt entry to weight measurement in the first summer/weight gain from smolt to measurement in the first summer; for further explanation, see text) with length of growth interval from smolt entry in the first summer. Arrows indicate method of determining feed conversion residual.

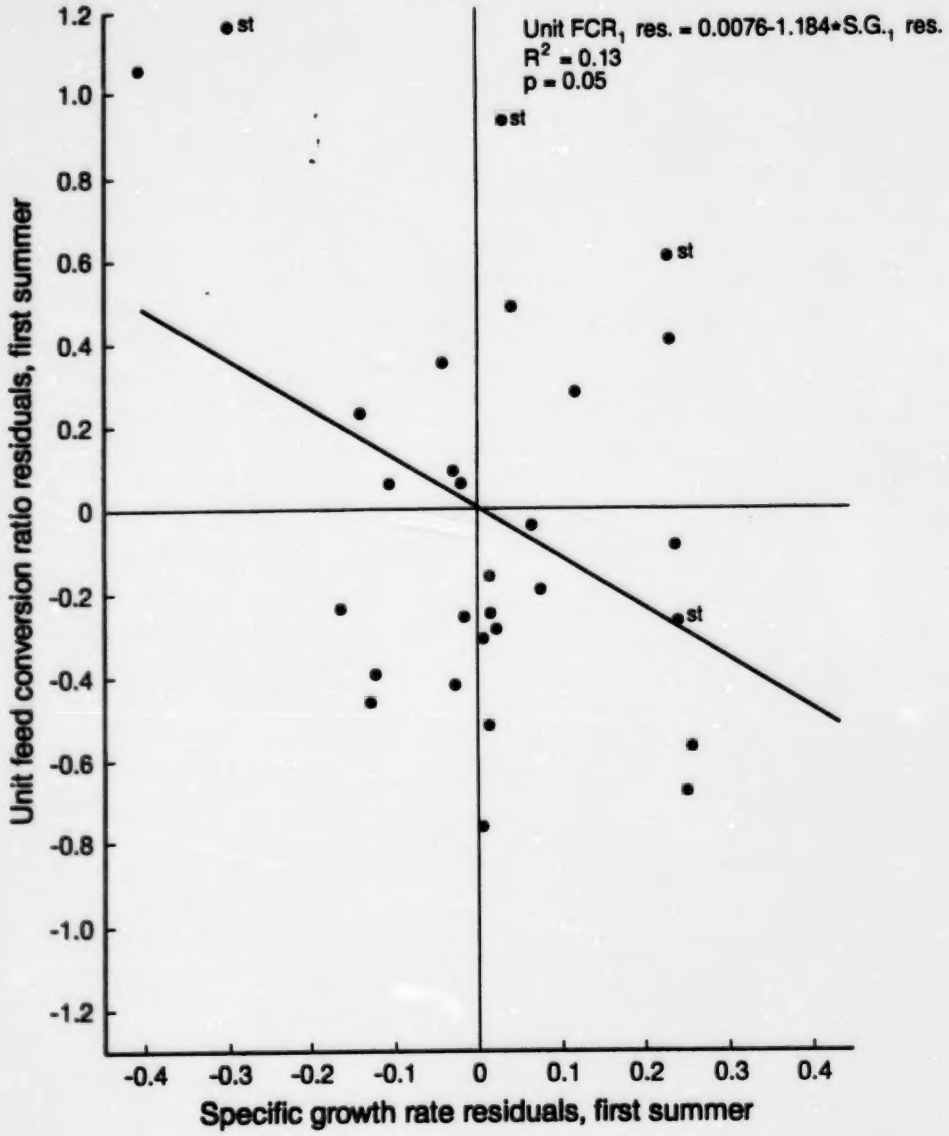


Fig. 55. Relationship between unit feed conversion residuals in the first summer and specific growth rate residuals (model 3) in the first summer. St: steel cages.

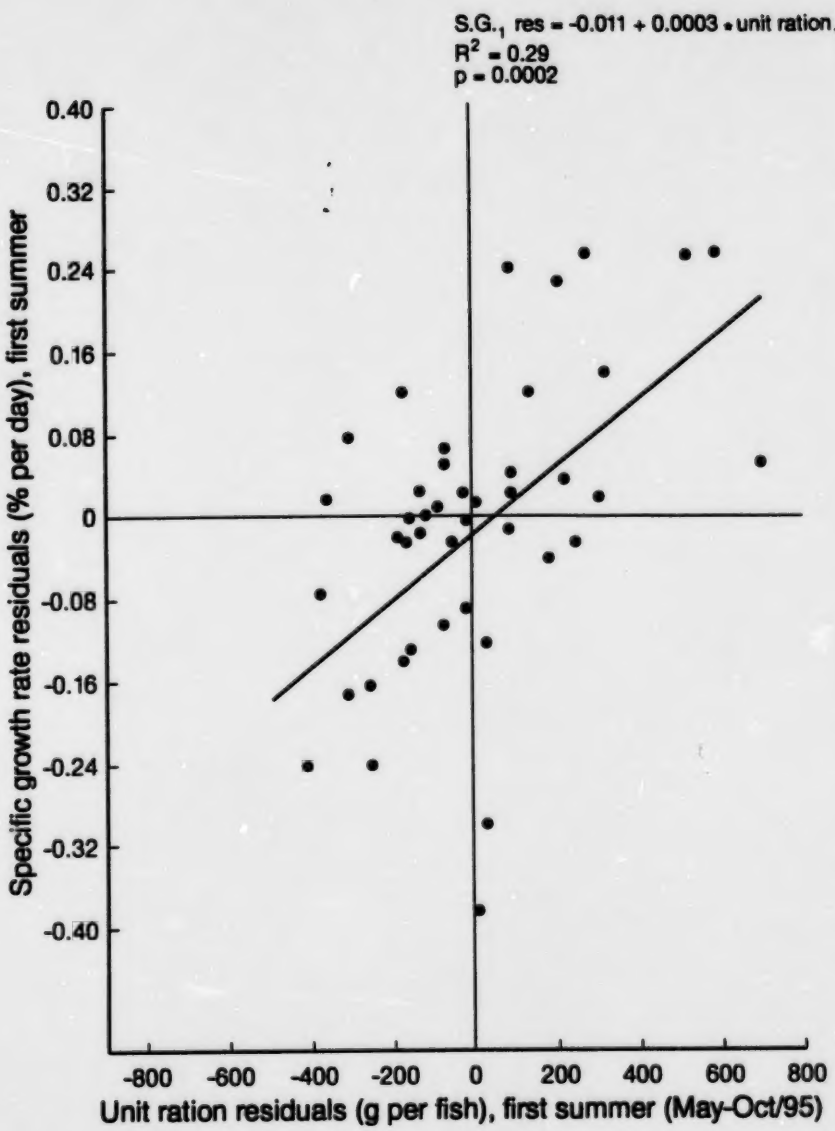


Fig. 56. Relationship between specific growth rate residuals (from Fig. 54), first summer and unit ration residuals (grams moisture-free feed per fish, for derivation, see text) for the first summer.

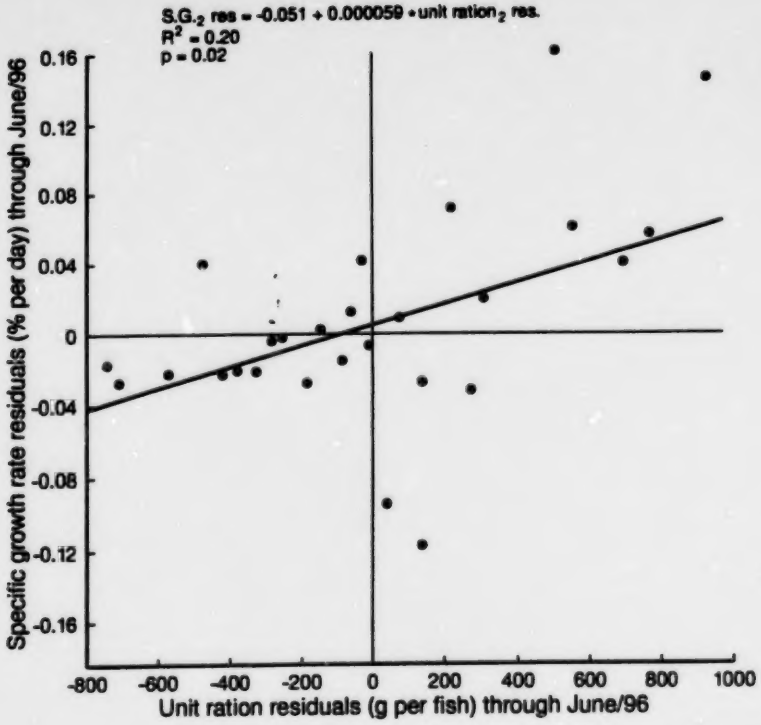


Fig. 57. As with Fig. 56, but for the growth interval from smolt entry (spring 1995) through June 1996.

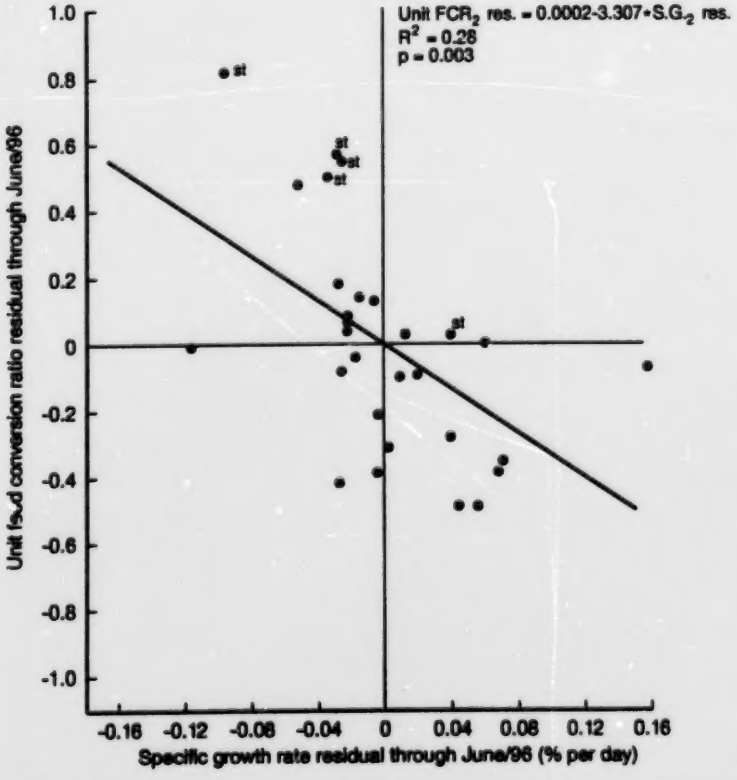


Fig. 58. As with Fig. 55, but for the growth interval from smolt entry (spring 1995 through June 1996). St: steel cages.

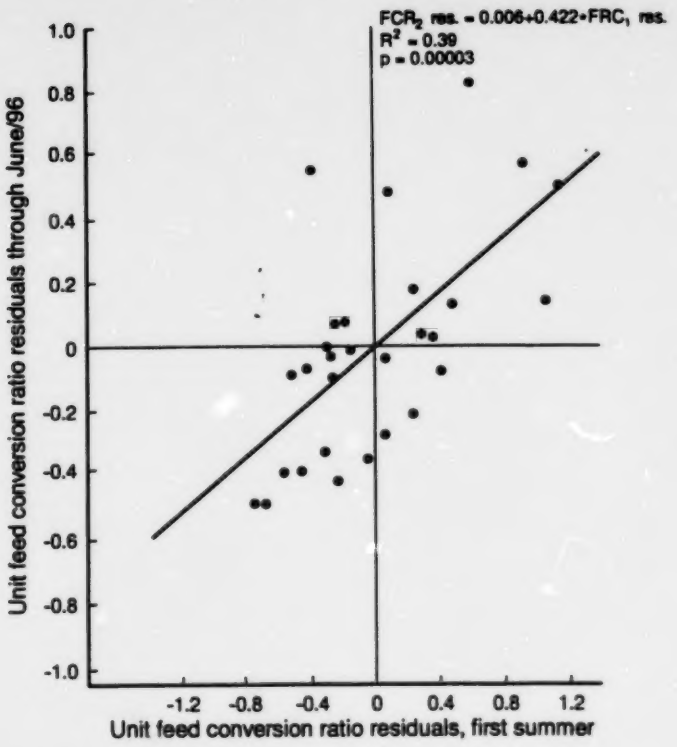


Fig. 59. Correlation between unit feed conversion ratio residuals through June 1996 and unit feed conversion residuals for the first summer. Cages fed most efficiently for the first summer tended to be fed most efficiently through June 1996 as well.

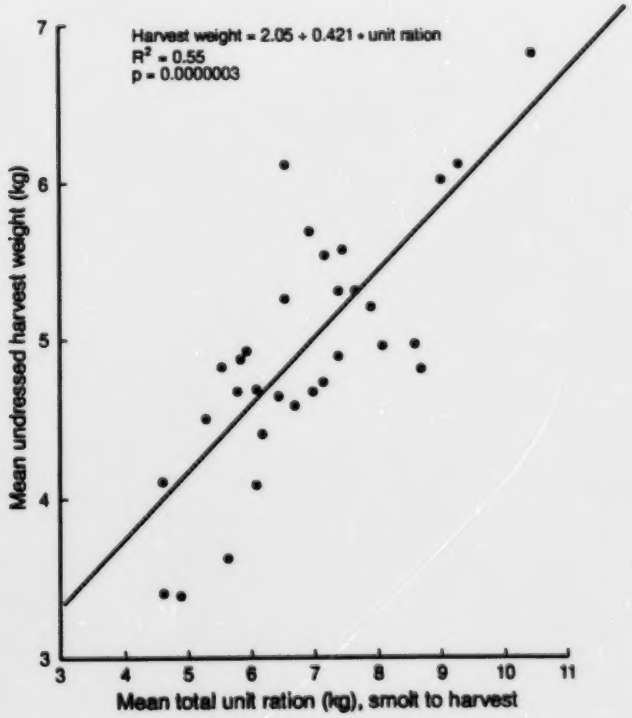


Fig. 60. Correlation between mean undressed harvest weight and mean total unit ration (kg moisture-free feed per fish from smolt entry to harvest). The more fish were fed, the bigger they were at harvest.

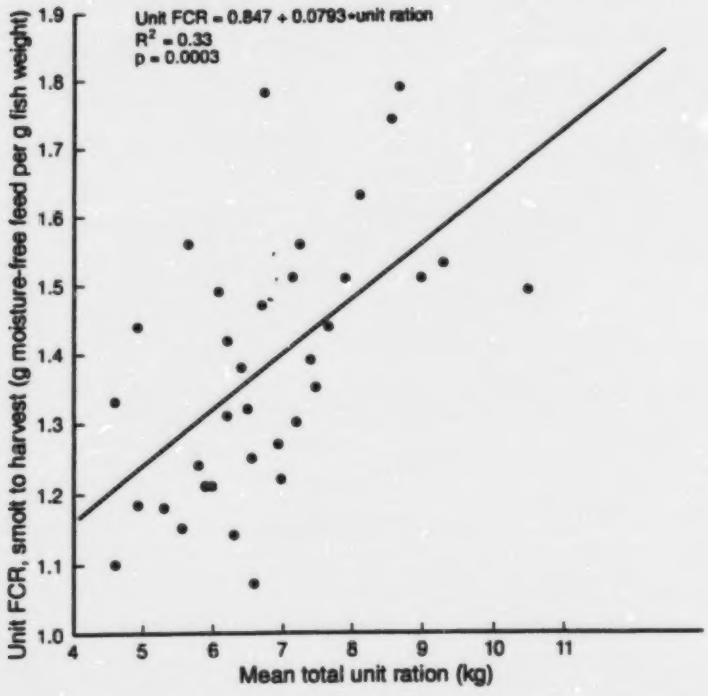


Fig. 61. Correlation between the unit FCR from smolt entry to harvest and mean total unit ration. For explanation, see text (mean total unit ration is not independent from time from smolt entry to harvest, hence seasonal effects on unit FCRs).

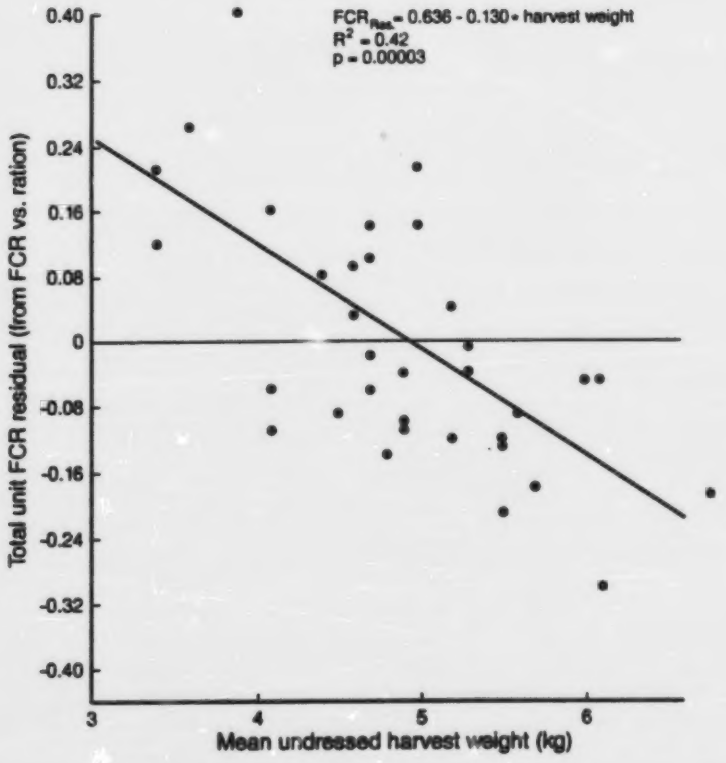


Fig. 62. Correlation between total unit FCR residual (from correlation between unit FCR and total unit ration of Fig. 61) and mean undressed harvest weight. Cages that had better (=lower) than industry average seasonally adjusted unit FCRs tended to produce bigger fish.

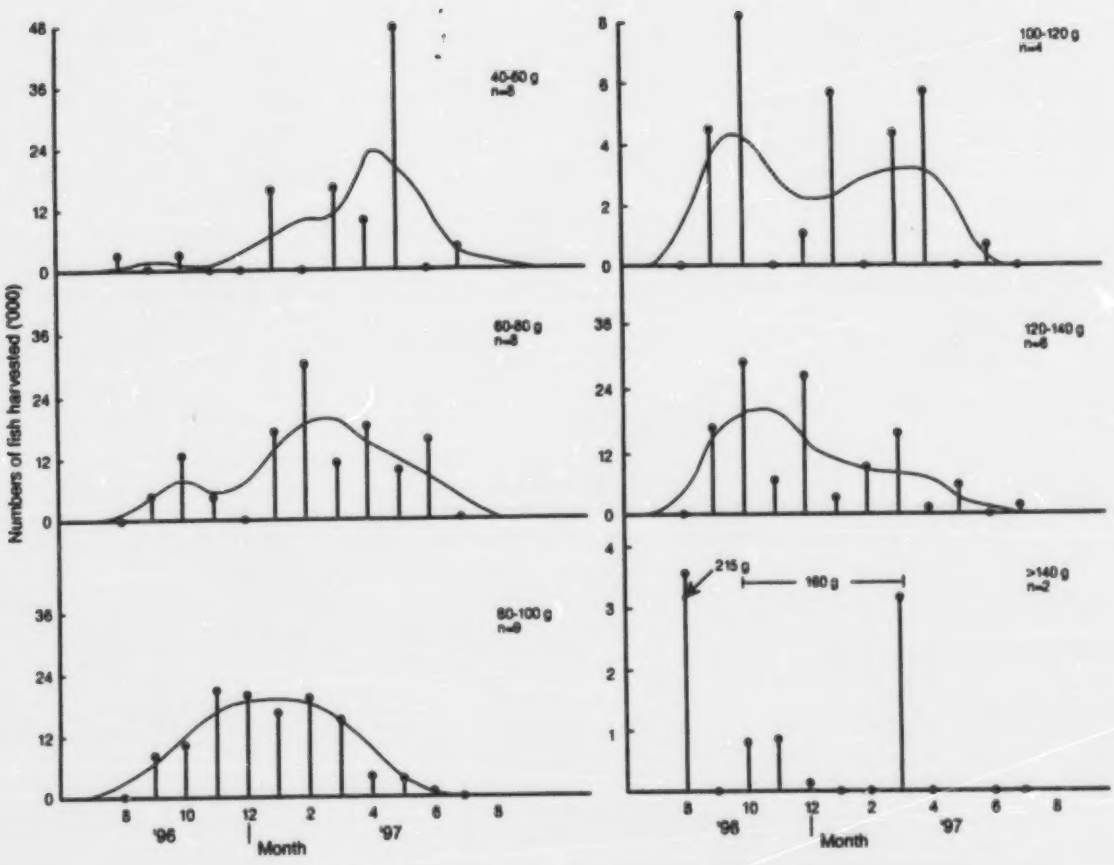


Fig. 63. Temporal harvest patterns for cages stocked with smolts of various size classes. N = number of cages for each size class. Smoothing lines are fitted by eye. The single cage of 215-g smolts was entirely harvested in August '96, while the cage of 160-g smolts was harvested over 6 mo.

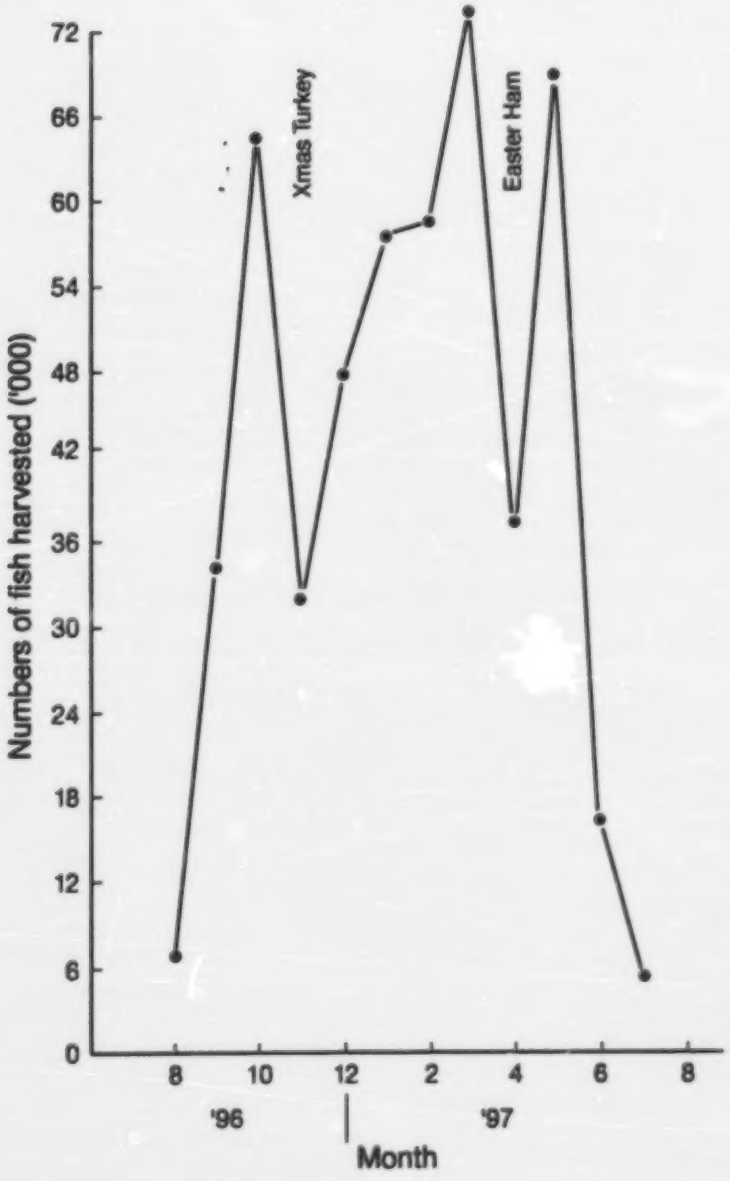


Fig. 64. Seasonal pattern of fish harvest from the monitored cages. Sales depressions are attributed to diversion of clients' diets from salmon during traditional holidays.

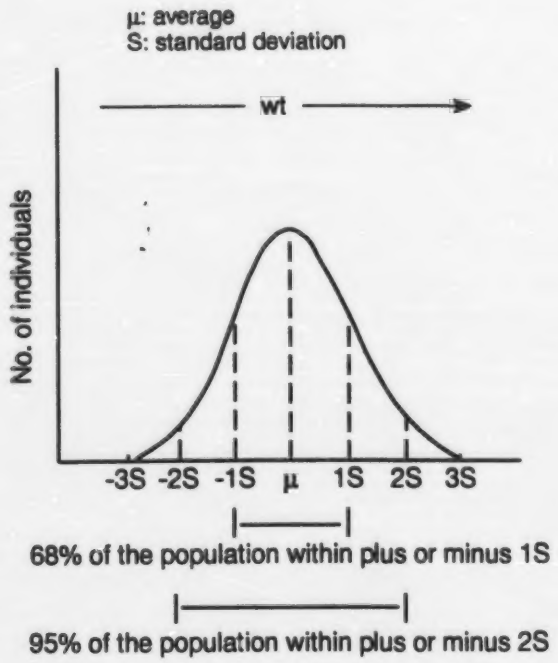

μ: average
S: standard deviation
wt
No. of individuals
-3S -2S -1S μ 1S 2S 3S
68% of the population within plus or minus 1S
95% of the population within plus or minus 2S

Fig. 65. Diagram of a "normal" distribution. S are standard deviation units, μ is the population mean or average.

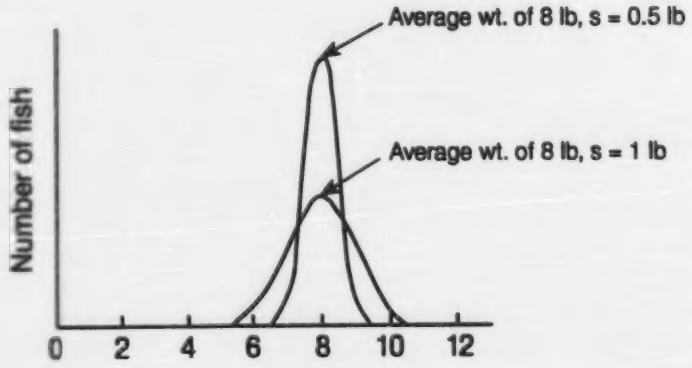


Fig. 66. Two normal populations with the same mean weight (8 lb), but differing standard deviations.

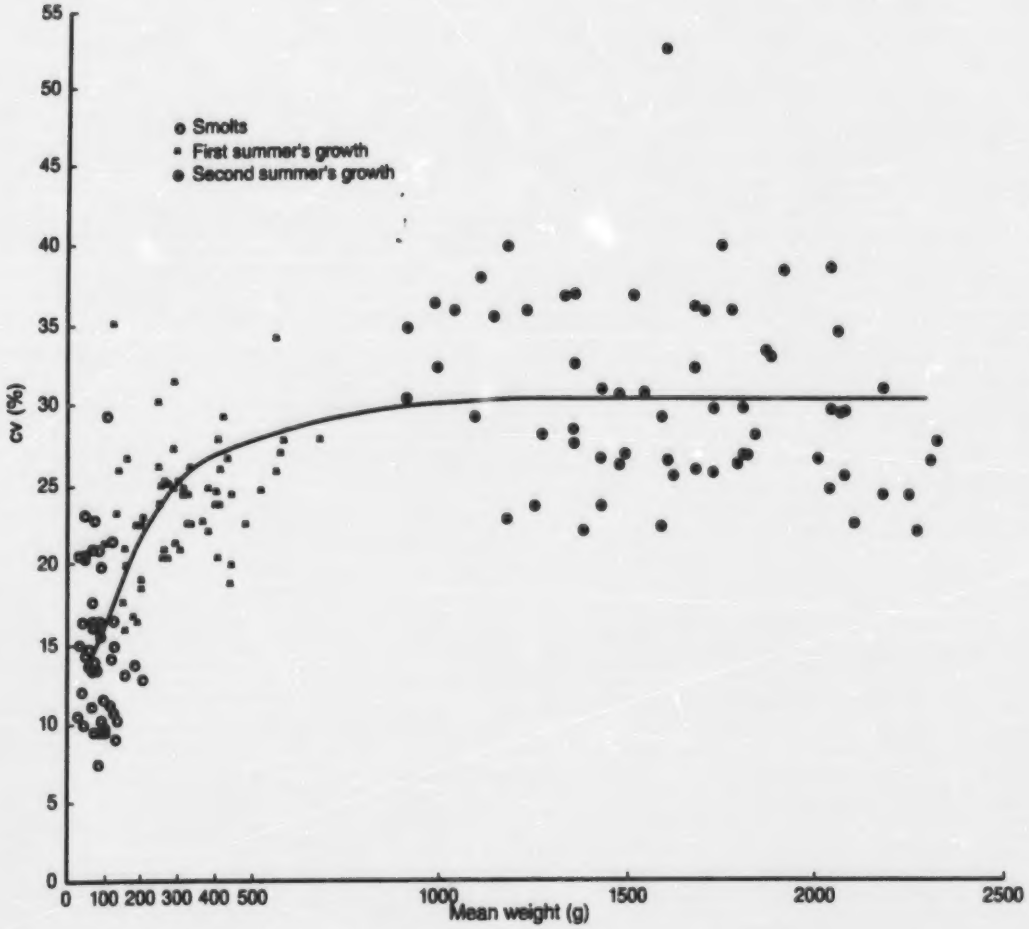


Fig. 67. Illustration of the increase in coefficients of variation (cv) (standard deviation as a percent of mean) of caged salmon in monitored cages over the growth cycle. Line is fitted by eye. Most of the increase in cv occurs in the first summer.

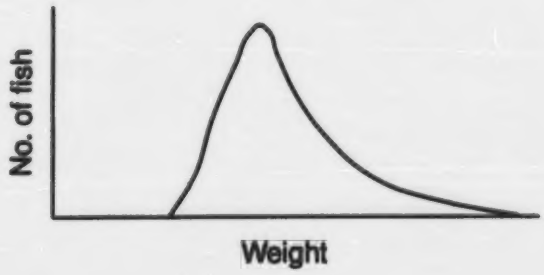


Fig. 68. Diagram of a skewed population (non-symmetrical, with a tail to the right).

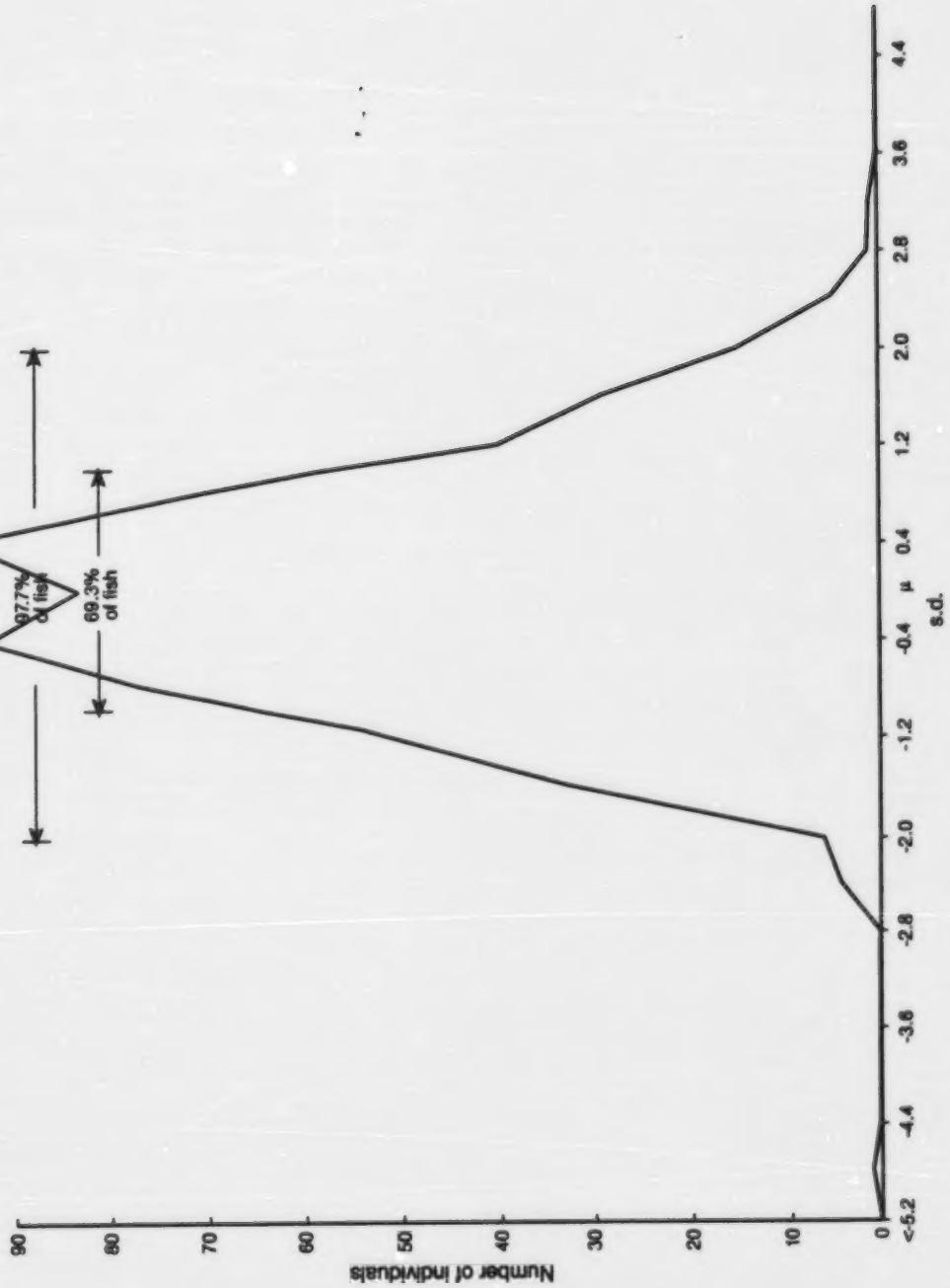


Fig. 69. A population curve generated from weights of 1700 smolts measured at the beginning of the study.

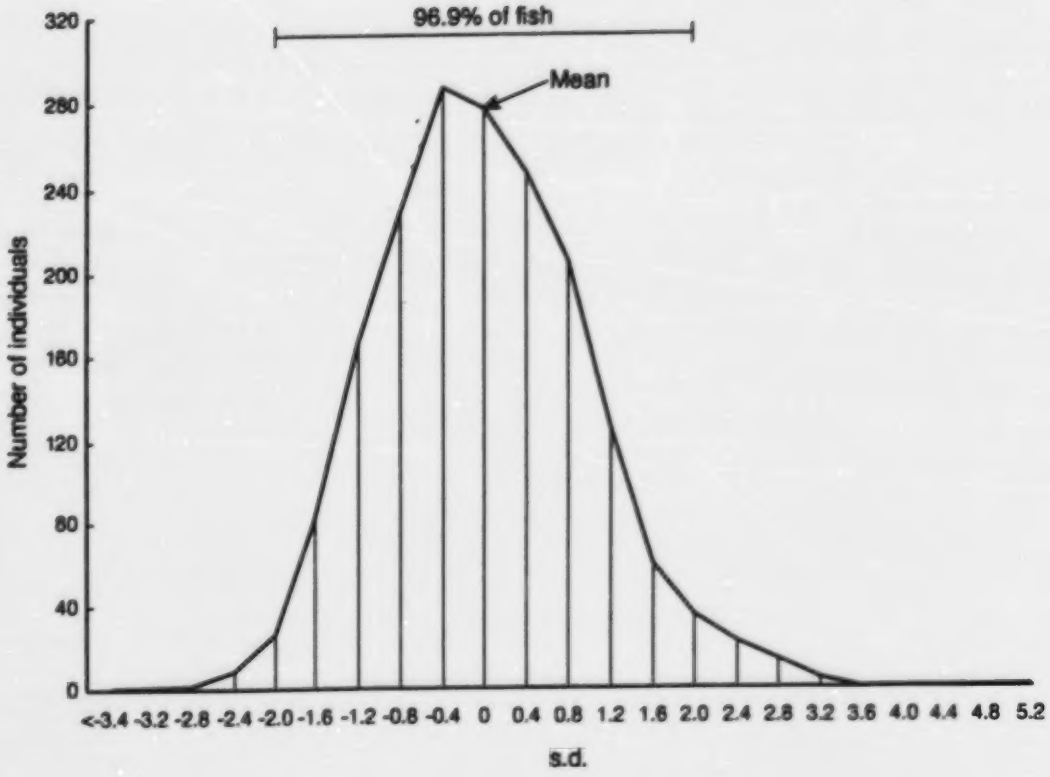


Fig. 70. A population curve of 1800 fish weighed early in the second summer of growth. The curve is slightly skewed to the right.

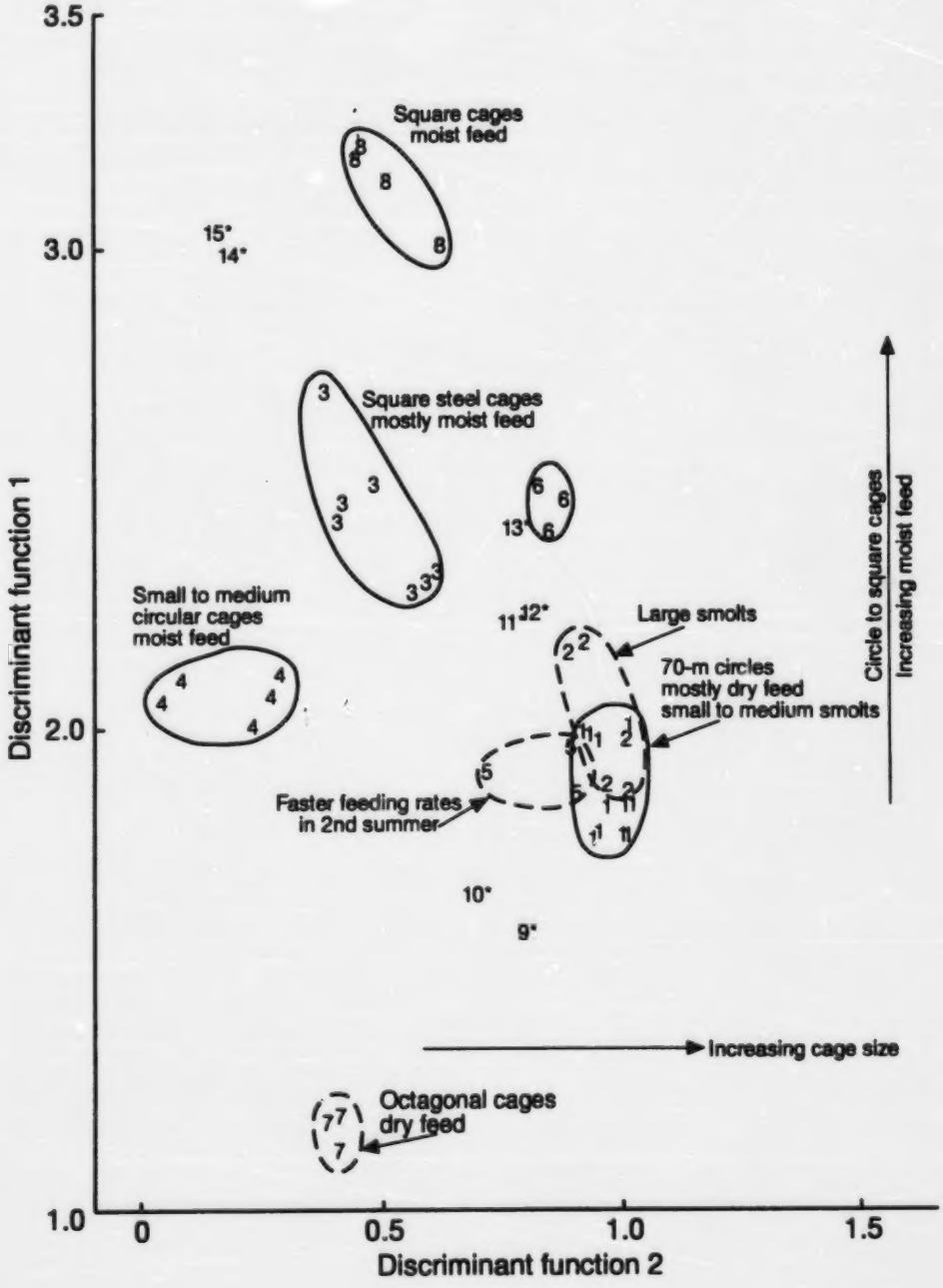


Fig. 71. A cluster analysis of surveyed cages, based upon a discriminant function analysis of husbandry variables. Clusters are located on a grid of the first two discriminant functions. Numbers in the clusters conform to the cluster numbers in the text. Numbers with asterisks are outliers. Arrows indicate significant variables influencing the first two discriminant functions.

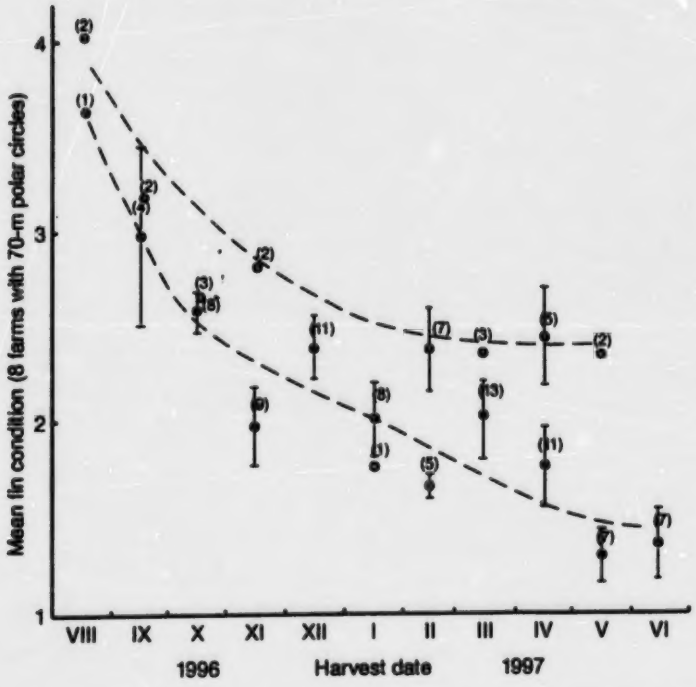


Fig. 72. Seasonal change in salmon fin condition for harvested immature fish from steel square (open circles) and 70-m circular plastic (closed circles) cages. Numbers in parentheses indicate samples of 50 fish each. Vertical bars are ±1 standard error.

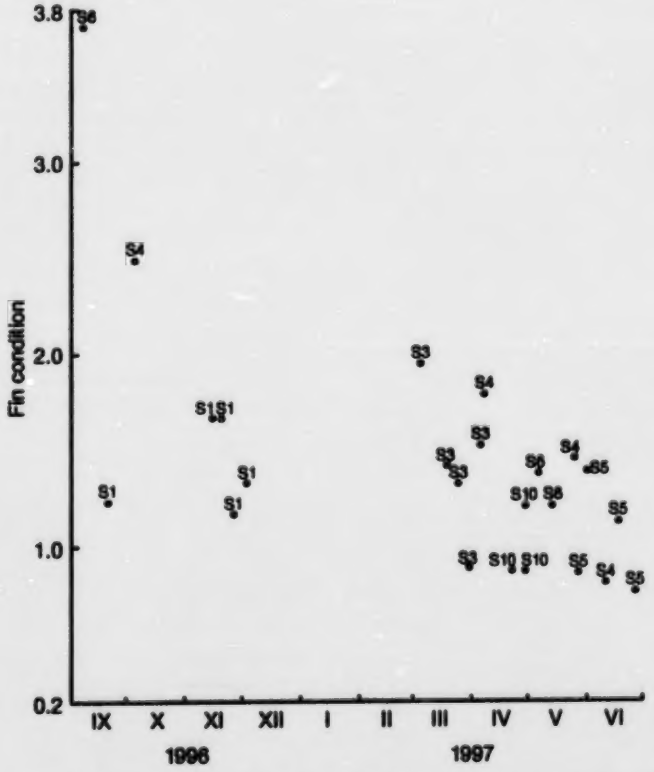


Fig. 73. Seasonal pattern of change in fin condition of immature fish for various cages at one salmon farm. Symbols are cage identifications.

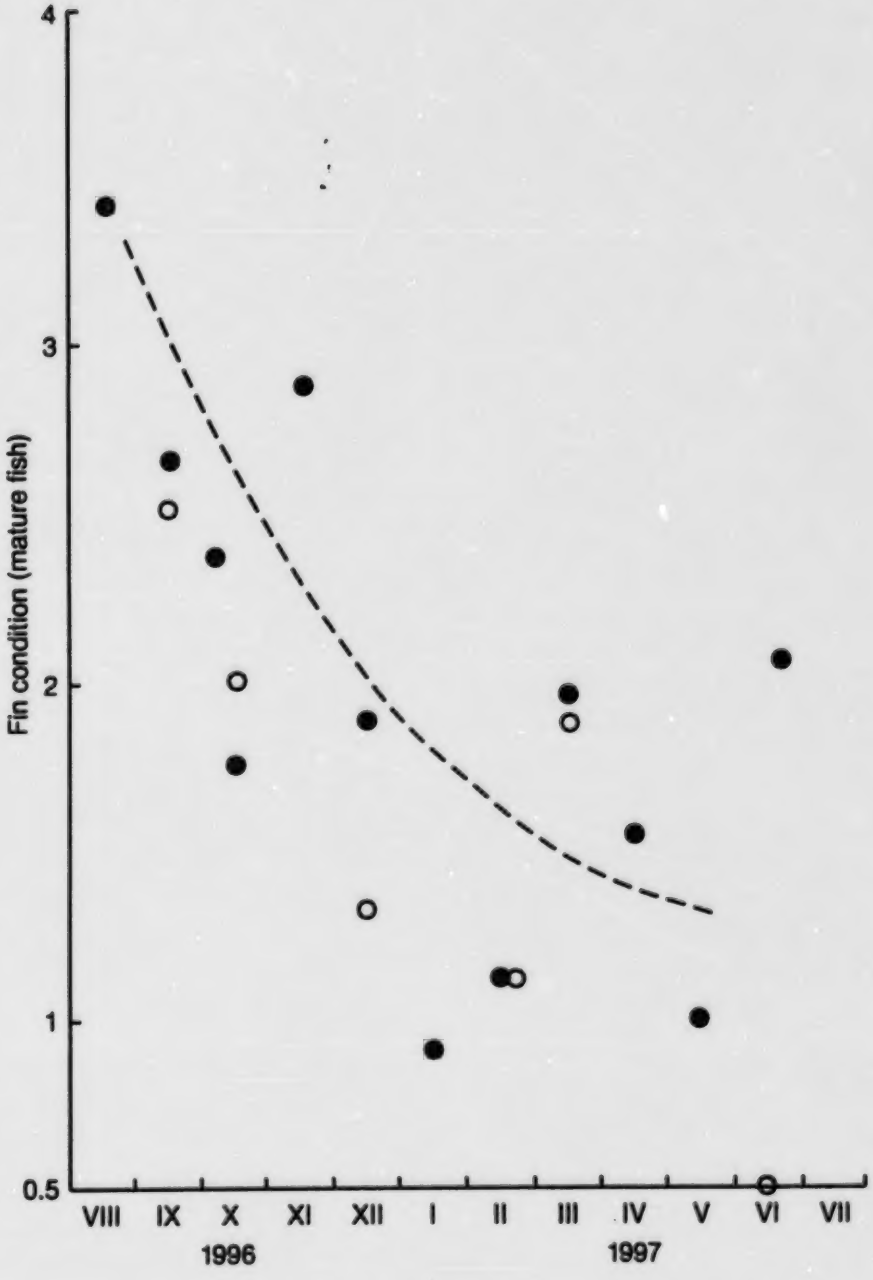


Fig. 74. Seasonal change in fin conditino of sexually mature fish. Open circles: females; closed circles: males.

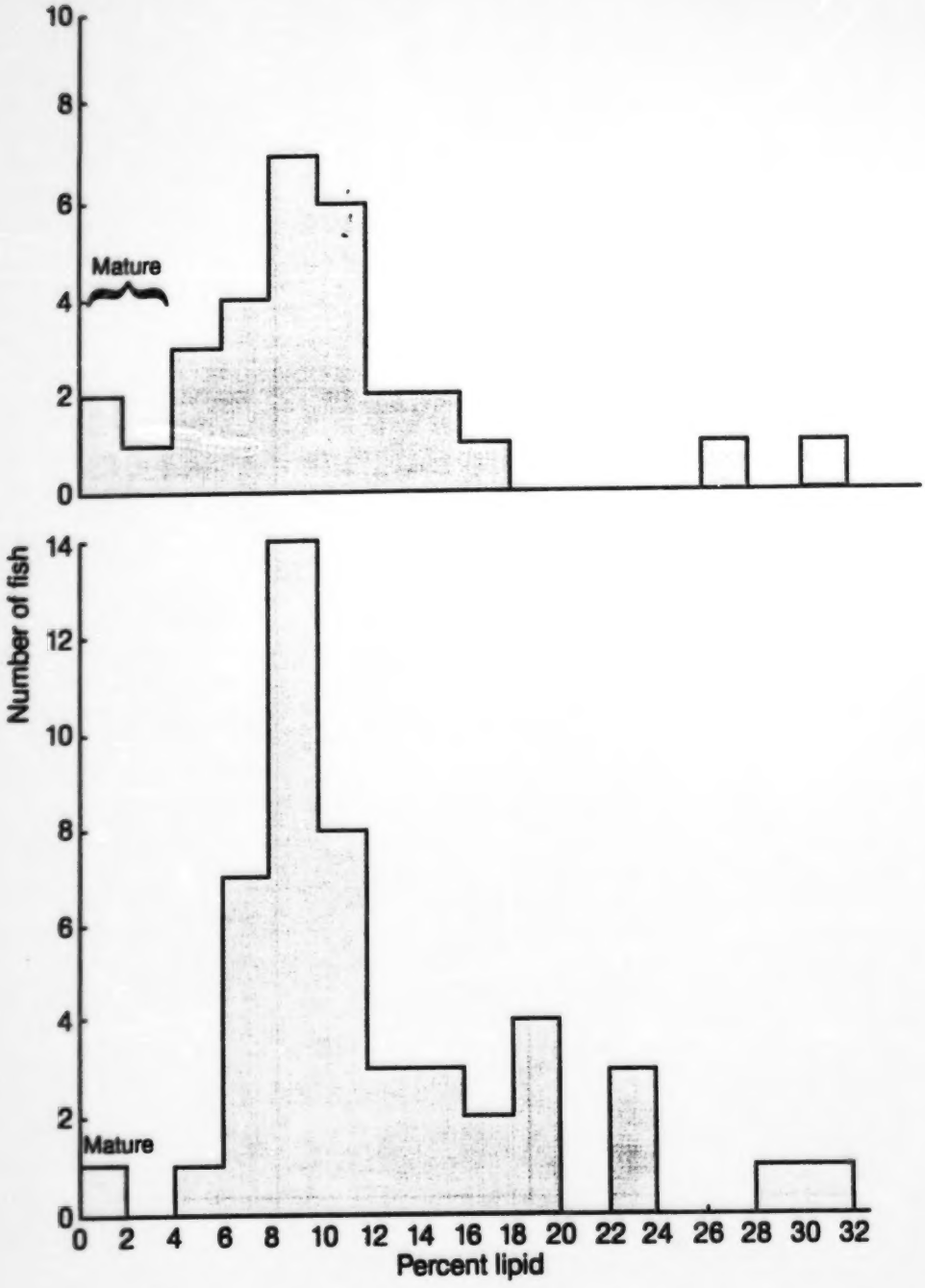


Fig. 75. Muscle lipid concentration of harvested salmon. Upper panel: males; lower panel: females.

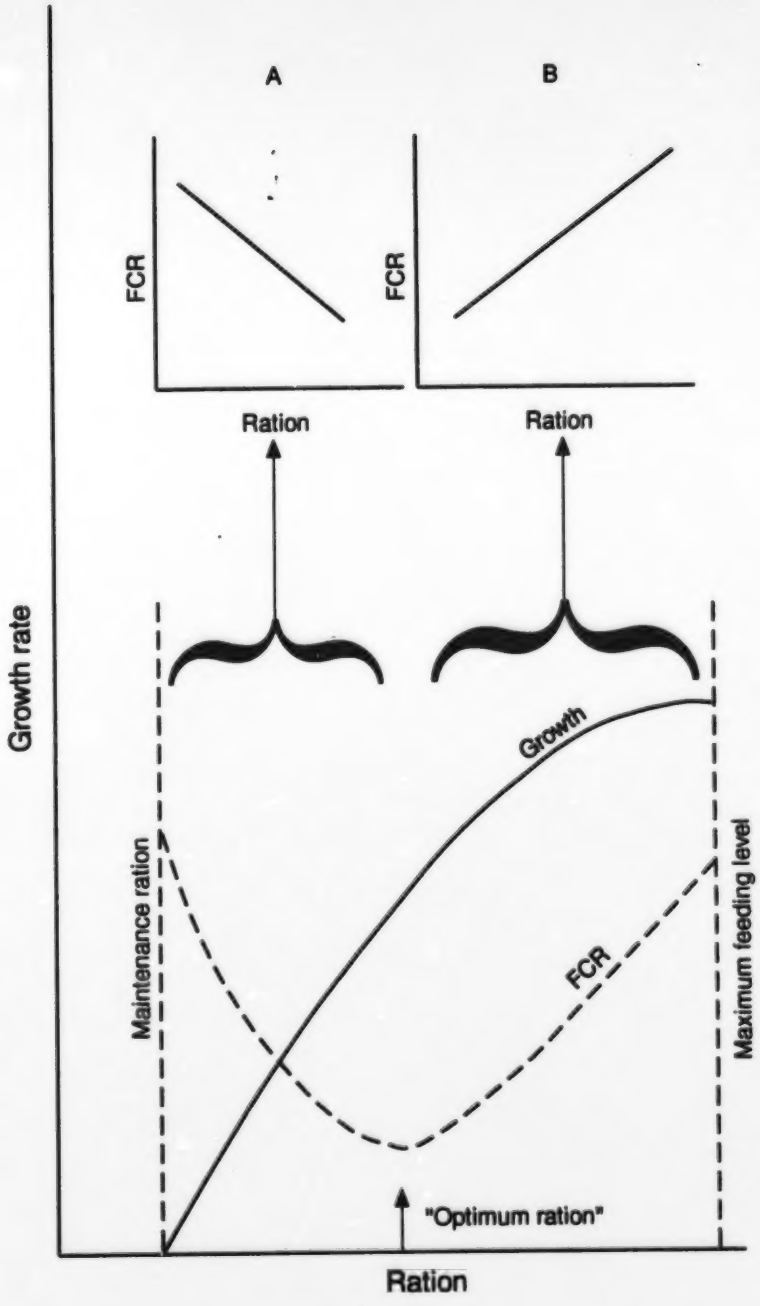
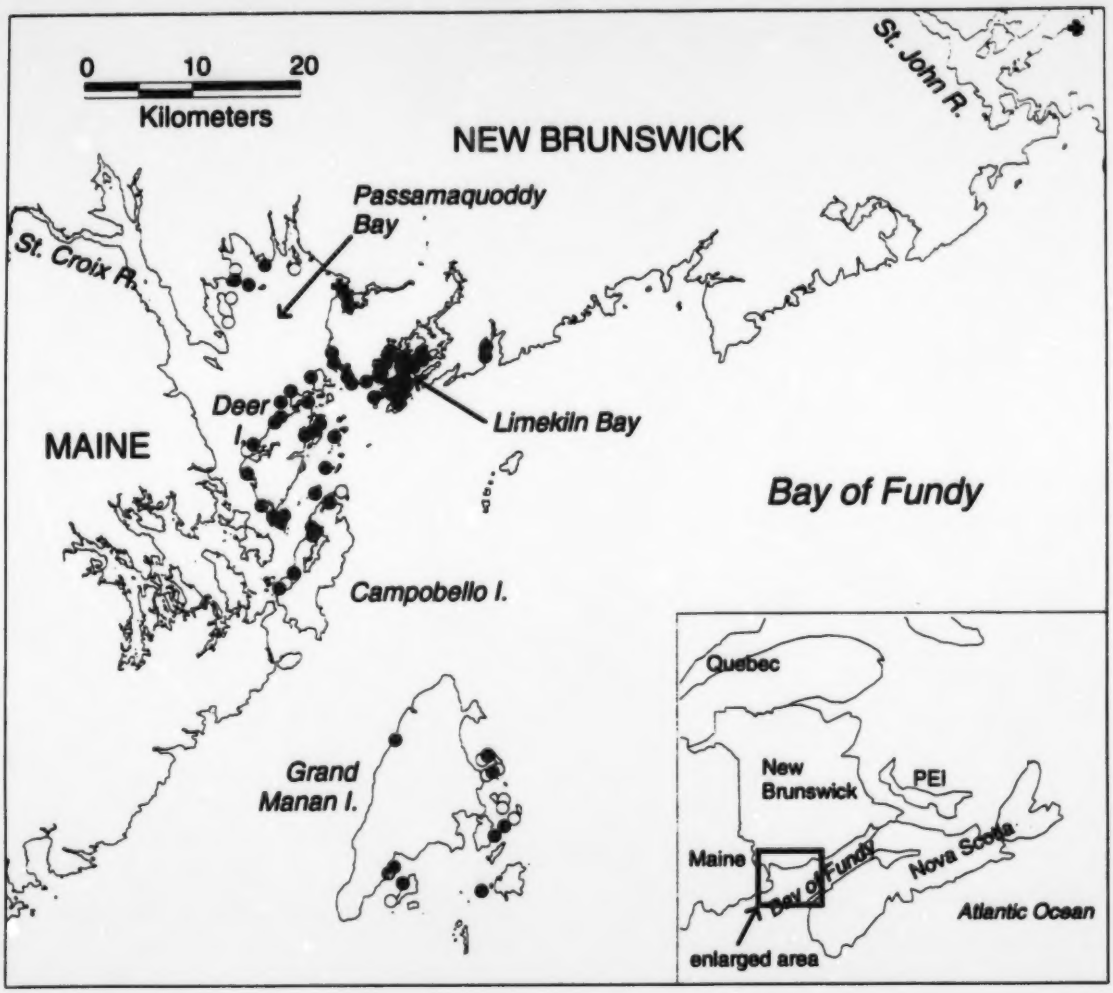


Fig. 76. Diagram of the relation between growth rate, feed conversion ratio and ration. Inset A: FCR-ration relationship at suboptimal rations. Inset B: FCR-ration relationsh at supraoptimal rations.



Appendix 1. Map showing locations of salmon aquaculture sites in southwestern New Brunswick during this study. • marine growout sites in 1995; • new marine growout sites in 1996; o new marine growout sites in 1997; + brackish water smolt acclimation sites.

Appendix 2

Title: Length-weight relationship of farmed Atlantic salmon (*Salmo salar* L.)

Authors: R.H. Peterson, J. Bailey, P. Harmon and A. Hanke

Introduction

Growing Atlantic salmon in sea cages is currently valued at greater than $100 million in the Bay of Fundy. Growing salmon efficiently requires reliable ways of periodically estimating growth performance. The two common measurements of fish size are weight and length, with weight measurements currently being the common method used by cage farmers in the Bay of Fundy to assess performance and to calculate probable marketing times. However, measures of weight alone may not provide the farmer with sufficient information.

Weight-length relationships are commonly combined in the "condition" factor(cf), where:

$$cf = (w/l^3) \times 100 \qquad \text{(Eq. 1)}$$

"Condition" is thus a measure of plumpness. Values of cf are typically near 1. Although this relationship is useful in comparing the conditions of fish of groups of fish of similar length, it can be misleading when assessing condition of salmon of varying lengths - as we shall show in the results section. We will present a refinement of the condition factor relationship which eliminates the size bias. We will also show the importance of monitoring condition of salmon to the fish farmer - particularly as the fish approach marketable size.

Methods

The data base for the calculations of the results section is the length-weight data of 5989 cultured salmon ranging in fork length from 18-83 cm and in weight from 60-6870 g. By using linear regression, a "standard" line for salmon in this range of sizes was calculated, and the parameters of this equation are used to refine the usual condition factor equation (Eq. 1).

We also accumulated length-weight data from 36 samples (50 fish per sample) of harvested salmon prior to gutting from 15 different salmon farms to examine the degree of condition factor variability among farms.

Lengths were measured to the nearest millimeter, and weights to the nearest gram.

Results and Discussion

The relationship between weight and length is linear if the logarithms of both measures are used. The equation for the 5898 salmon lengths and weights is:

$$\text{Log weight} = -2.1674 + 3.1281 \log \text{length} \qquad \text{(Eq. 2)}$$

The fit is excellent (R^2=0.988).

The traditional condition factor relationship used ($cf = (w/l^3) \times 100$) assumes that the equation relating log length and log weight is:

$$\text{Log weight} = 2.000 + 3.000 \log \text{length} \qquad \text{(Eq. 3)}$$

If the coefficients are not exactly 2 and 3, then a size bias is incorporated into condition factor estimates.

The modified condition factor is obtained simply by re-arranging Eq. 2:

$$cf(m) = \text{antilog}(\log \text{weight} - 3.1281 \log \text{length} + 2.1674) \qquad \text{(Eq. 4)}$$

and are constant at 1.000 for the average fish as derived from Eq. 2.

The disadvantage of the traditional condition factor to the salmon farmer is that it provides a variable base for assessing fish performance, creating some uncertainty when comparing conditions of groups of salmon of differing mean lengths. We have essentially used the database of 5898 lengths and weights to establish a "standard" line for salmon with a condition factor of 1.0.

We should emphasize that this "standard" equation does not necessarily represent an ideal weight-length relationship for salmon. In fact, most marketed salmon have higher condition factors than those from which we derived the line. The derived line merely provides a standard to compare performance that is constant over essentially the full size range of cage-reared salmon.

The importance of fish condition is emphasized when length-weight relationships of harvested salmon are considered. Modified condition factors range from less than 1.0 to nearly 1.25. For salmon of a given length, this can represent a difference of 0.75-1.00 kg per fish. At sales prices of near $6.00 per kg, then variation in condition factor among lots of harvested fish at a given length can result indifferences of $4-6 per fish. These calculations are a simplification, as they do not take into account possible differences in food conversion.

Acknowledgments

We wish to acknowledge the cooperation of the fish farmers and processors who allowed us to collect the data presented here. We are also indebted to F. O'Flynn and J. Bailey of the Atlantic Salmon Federation who kindly provided us with the length-weight data base.